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ABSTRACT

This guide has been developed through a collaborative effort involving the U.S. Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). It is part of an ongoing commitment to ensure that the results of scientific research on ozone depletion are effectively applied to individual and societal decision-making. This guide is intended for use by science teachers, environmental educators, and teacher trainers in planning and conducting classes and activities on ozone depletion and also for use by individuals who conduct informal educational activities to the general public through community groups, museums, business clubs, libraries, and extension programs. It provides educators with the requisite background on the science of ozone depletion as well as lesson plans and activities. It is organized into three primary categories: background information on the science of ozone depletion, teaching activities and tools, and pamphlets describing action steps to protect the ozone layer. The materials in the guide are best-suited for high school students through college and adults, but can be adapted to meet the needs of lower grade levels. (JRH)

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Ozone Layer Educator's Guide

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Preface

This Ozone Layer Educator's Guide has been developed through a collaborative effort involving the U.S. Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). It is part of an ongoing commitment to ensure that the results of scientific research on ozone depletion are effectively applied to individual and societal decision-making. Furthermore, it reflects the agencies' mission of increasing human understanding of the environment, and improving our partnership with the Earth's natural processes.

This educator's guide is intended for use by science teachers, environmental educators, and teacher trainers in planning and conducting classes and activities on ozone depletion. While the materials are best-suited for high-school students through college and adults, they can also be adapted to meet the needs of lower grade levels. Equally important, the guide is also intended for use by individuals who conduct informal educational activities to the general public through community groups, museums, business clubs, libraries and extension programs.

The guide consists of materials drawn from a range of sources, with the goal of providing educators with both the requisite background on the science of ozone depletion, as well as lesson plans and activities. This guide is not intended to be a comprehensive presentation of all the issues pertaining to the subject. However, the scientific materials do represent the most recent information available on ozone depletion. It is our hope that the suggested activities facilitate teaching and engage your audience, and help to frame and clarify some of the key issues associated with this environmental issue.

All the included materials have been subjected to a set of review criteria including: scientific accuracy and timeliness, consistency with national science education goals and standards and clarity. The guide was reviewed by each of the contributing agencies as well as experts in atmospheric science and ozone depletion, and professional educators. It has been organized into 3 primary categories: background information on the science of ozone depletion, teaching activities and tools, and pamphlets describing action steps to protect the ozone layer. Materials have been provided by all of the government agencies that developed this kit.

The guide was initially developed to commemorate Ozone Layer Awareness Week (Sept. 16-23, 1995), but the materials are timeless and may be used in the future. We encourage you to do so. All materials may be duplicated for educational purposes. Because of collating difficulties due to the materials' numerous sources, the pieces have not been arranged in the ideal sequence. However, the following Table of Contents provides the suggested order in which you may wish to organize the guide in a binder. Further information is available at the Stratospheric Ozone Information Hotline (1-800-296-1996), and on the EPA Stratospheric Protection Division homepage http:\\www.epa.gov/docs/ozone/index.html. Please encourage your students to take this information home with them to share with their families.

Ozone Layer Educator's Guide
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United States
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Agency

Office of Air and Radiation
Stratospheric Protection Division
6205J

July 1995

Ozone Depletion: Science in the Service of Society

Background

Two decades ago stratospheric ozone depletion was mainly of interest to atmospheric scientists - today it is a world-wide environmental concern. Destruction of the ozone layer is global in impact, and it is the direct but unintended result of human activity.

Changes in the Earth's system, both natural and human induced, have profound implications for the future. As such, it is vital that we strive to understand these environmental processes and relationships.

There may be some confusion as to the role of ozone. In brief, naturally occurring ozone in the upper atmosphere (the stratosphere) is good. It filters out harmful ultraviolet (UV) radiation from the sun. In contrast, ground-level ozone (smog) is bad. The byproduct of fossil fuel emissions, excessive ground-level ozone is an air-pollutant that affects plants and human health.

Several groups are important to the process of building the scientific foundation for our understanding of changes in the global environment. In the United States, 13 federal agencies are responsible for the U.S. Global Change Research Program (USGCRP). This federal program coordinates U.S. research on ozone depletion. Internationally, the scientific community periodically prepares a review of the "state of the science" on ozone depletion, under the sponsorship of the United Nations Environment Programme and World Meteorological Organization.

Almost 300 scientists worldwide drafted and reviewed the latest of these reports, the WMO/UNEP *Scientific Assessment of Ozone Depletion:1994*. Through this assessment process, a remarkable international consensus among scientists has emerged.

The Problem

The strong consensus is that certain human-made chemicals including chlorofluorocarbons (CFCs) are destroying the stratospheric ozone layer, which protects the Earth from harmful ultraviolet (UV) radiation from the sun. Increased UV radiation heightens the incidence of human skin cancer, cataracts, and weakened immune systems, and it also endangers the environment by threatening important crop yields, and other plant and animal life.

Depletion of ozone has been documented over Antarctica (known as the "Antarctic Ozone Hole"), and ozone losses of 5 to 10 percent, depending on season, have also occurred over North America. Global levels of stratospheric ozone have decreased by almost 5% since 1979.

Ozone-depleting chemicals are very stable in the lower atmosphere. This enables them to survive long enough to reach the stratosphere, where ultraviolet radiation from the sun causes them to break apart and release chlorine and bromine atoms.

These highly reactive atoms then react with ozone, starting chemical cycles of ozone destruction that deplete the ozone layer. One chlorine atom can destroy more than 100,000 ozone molecules; bromine is 40 times more efficient in its catalytic cycles. The continued build-up of CFCs and other ozone-depleting chemicals has led to worldwide losses of stratospheric ozone.

The Science

Our scientific knowledge has increased tremendously over the last two decades based on the federal, international, and private commitment to research. Based on this knowledge, EPA, other federal agencies, and the private sector are taking actions to prevent further ozone depletion. More research, however, is necessary to ensure a sound scientific foundation.

o With atmospheric chlorine levels expected to peak within the next few years, what will be the global ozone losses and surface UV changes in the next 20-30 years?

o What ozone losses and surface UV increases could occur in the Arctic and the Antarctic during the same time period?

o What are the global climate impacts of the Antarctic ozone hole, which is expected to last well into the next century?

o What are the environmental effects of new substitute chemicals?

A well-founded scientific understanding is critical for national and international environmental policy development to ensure the social and economic health of future generations.

Providing a Sustainable Future

Under authority of the Clean Air Act, the EPA has created a regulatory program to protect the ozone layer. A cornerstone of this program is market-based production permits, culminating in the complete phaseout of chlorofluorocarbons (CFCs) in 1996. The program also includes product labeling, mandatory recycling and recovery while repairing equipment, bans on non-essential products, and a program to review the health and environmental acceptability of alternatives.

The U.S. was one of the first countries to ban CFCs in aerosols in the 1970s, and U.S. production of ozone-depleting substances has declined significantly since 1988, reaching levels comparable to those of 30 years ago. These domestic initiatives are part of a larger, global effort. The Montreal Protocol on Substances that Deplete the Ozone Layer is the international treaty to protect the ozone layer, and today there are 150 Parties (signatories). Under this treaty, CFC production in all industrialized countries will cease January 1, 1996. Only recycled and stockpiled CFCs will be available for use after this date. This production phaseout is possible because of efforts to ensure that there are substitute chemicals and technologies available for all CFC uses.

The benefits of these national and international efforts are beginning to become apparent. Recent data confirm that the rate of growth of atmospheric concentrations of CFCs has begun to decline substantially, with peak levels expected before the turn of the century. This global effort has slowed the build-up of ozone depleting chemicals in the atmosphere, and will soon have successfully started the process to recovery. By continuing research, and taking steps to protect the ozone layer, we are safeguarding the environment as well as the health and prosperity of future generations.

NASA Facts

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771
AC 301 286-8955

December 1993

NF-198

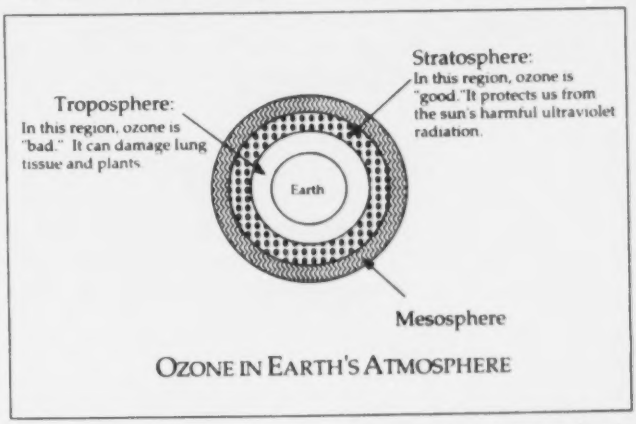
The Mission to Planet Earth Series

These articles consider Earth's many dynamic processes and their interactions.

Ozone: What is it, and why do we care about it?

Ozone is a relatively unstable molecule found in Earth's atmosphere. Most ozone is concentrated below a 30-mile (48-km) height. An ozone molecule is made up of three atoms of oxygen. Although it represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth.

Depending on where ozone resides, it can protect or harm life on Earth. High in the atmosphere—about 15 miles (24 km) up—ozone acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation. Without this shield, we would be more susceptible to skin cancer, cataracts and impaired immune systems. Closer to Earth, in the air we breathe, ozone is a harmful pollutant that causes damage to lung tissue and plants.


Troposphere:
In this region, ozone is "bad." It can damage lung tissue and plants.
Stratosphere:
In this region, ozone is "good." It protects us from the sun's harmful ultraviolet radiation.
Earth
Mesosphere

OZONE IN EARTH'S ATMOSPHERE

The amounts of "good" and "bad" ozone in the atmosphere depend on a balance between processes that create ozone and those that destroy it. An upset in the ozone balance can have serious consequences for life on Earth. Scientists are finding evidence that changes are occurring in ozone levels—the "bad" ozone is increasing in the air we breathe, and the "good" ozone is decreasing in our protective ozone shield. This article describes processes that regulate "good" ozone levels.

Ozone Balance in the Stratosphere

About 24 kilometers up in the atmosphere, in the region called the stratosphere, ozone is created and destroyed primarily by ultraviolet radiation. The air in the stratosphere is bombarded continuously with ultraviolet radiation from the sun. When high energy ultraviolet rays strike molecules of ordinary oxygen (O_2), they split the molecule into two single oxygen atoms, known as atomic oxygen. A freed oxygen atom then can bump into an oxygen molecule (O_2), and form a molecule of ozone (O_3).

The characteristic of ozone that makes it so valuable to us—its ability to absorb a range of ultraviolet rays—also causes its destruction. When an ozone molecule (O_3) absorbs even low energy ultraviolet radiation, it splits into an ordinary oxygen molecule (O_2) and a free oxygen atom (O). The free oxygen atom then may join up with an oxygen molecule to make another ozone molecule, or it may steal an oxygen atom from an ozone molecule to make two ordinary oxygen molecules. Some scientists call these processes of ozone production and destruction, initiated by ultraviolet radiation, the "Chapman Reactions."

Natural forces other than the Chapman Reactions also affect the concentration of ozone in the stratosphere. Because ozone is a highly unstable molecule, it reacts very easily, readily donating its "extra" oxygen molecule to nitrogen, hydrogen and chlorine found in natural compounds. These elements always have existed in the stratosphere, released from sources such as soil, water vapor and the oceans.

In addition, scientists are finding that ozone levels change periodically as part of regular natural cycles such as the changing seasons, sun cycles and winds. Moreover, volcanic eruptions may inject materials into the stratosphere that can destroy ozone.

Over the Earth's lifetime, natural processes have regulated the balance of ozone in the stratosphere. A simple way to understand the ozone balance is to think of a leaky bucket. As long as water is poured into the bucket at the same rate that water is leaking out, the amount of water in the bucket will remain the same. Likewise, as long as ozone is being created at the same rate that it is being destroyed, the total amount of ozone will remain the same.

In the past two decades, however, scientists have found evidence that human activities are disrupting the ozone balance. Human production of chlorine-containing chemicals such as chlorofluorocarbons (CFCs) has added an additional force that destroys ozone. CFCs are compounds made up of chlorine, fluorine and carbon bound together. Because they are such stable molecules, CFCs do not react easily with other chemicals in the lower atmosphere. One of the few forces that can break up CFC molecules is ultraviolet radiation. In the lower atmosphere, however, CFCs are protected from ultraviolet radiation by the ozone layer. CFC molecules thus are able to migrate intact up into the stratosphere. Although the CFC molecules are heavier than air, the mixing processes of the atmosphere carry them into the stratosphere.

High energy ultraviolet radiation strikes an oxygen molecule...
...and causes it to split into two free oxygen atoms.
The free oxygen atoms collide with molecules of oxygen...
...to form ozone molecules.
Ozone absorbs a range of ultraviolet radiation...
...splitting the molecule into one free oxygen atom and one molecule of ordinary oxygen.
The free oxygen atom then can collide with an ozone molecule...
...to form two molecules of oxygen.

Once in the stratosphere, however, the CFC molecules no longer are shielded from ultraviolet radiation by the ozone layer. Bombarded by the sun's ultraviolet energy, CFC molecules break up and release their chlorine atoms. The free chlorine atoms then can react with ozone molecules, taking one oxygen atom to form chlorine monoxide and leaving an ordinary oxygen molecule.

If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs probably would pose very little threat to the ozone layer. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom breaks up the chlorine monoxide, stealing the oxygen atom and releasing the chlorine atom back into the stratosphere to destroy more ozone. This reaction happens over and over again, allowing a single atom of chlorine to destroy many molecules of ozone.

Fortunately, chlorine atoms do not remain in the stratosphere forever. When a free chlorine atom reacts with gases such as methane (CH_4), it is bound up into a molecule of hydrogen chloride

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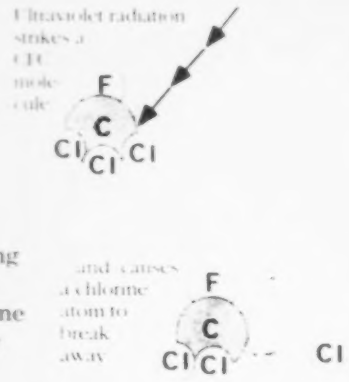
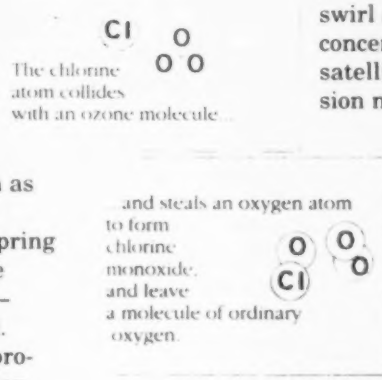
(HCl), which can be carried from the stratosphere into the troposphere, where it can be washed away by rain. Therefore, if humans stop putting CFCs and other ozone-destroying chemicals into the stratosphere, the ozone layer eventually may repair itself.



Ozone Depletion

The term "ozone depletion" means more than just the natural destruction of ozone, it means that ozone loss is exceeding ozone creation. Think again of the "leaky bucket." Putting additional ozone-destroying compounds such as CFCs into the atmosphere is like causing the "bucket" of ozone to spring extra leaks. The extra leaks cause ozone to leak out at a faster rate—faster than ozone is being created. Consequently, the level of ozone protecting us from ultraviolet radiation decreases.


Cl
O
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The chlorine atom collides with an ozone molecule...
...and steals an oxygen atom to form chlorine monoxide, and leave a molecule of ordinary oxygen.
O
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Cl
When a free atom of oxygen collides with the chlorine monoxide...
O
O
Cl
...the two oxygen atoms form a molecule of oxygen. The chlorine atom is thus released and free to destroy more ozone.
O
Cl
O

In the area over Antarctica, stratospheric clouds hold ice particles that are not present at warmer latitudes. Reactions occur on the surface of the ice particles that accelerate the ozone destruction caused by stratospheric chlorine. This phenomenon has caused documented decreases in ozone concentrations over Antarctica. In fact, ozone levels drop so low in spring in the southern hemisphere that scientists have observed what they call a "hole" in the ozone layer.

In addition, scientists have observed declining concentrations of ozone over the whole globe. In the second half of 1992, for example, world-wide ozone levels were the lowest ever recorded.

Monitoring Ozone from Space

Since the 1920's, ozone has been measured from the ground. Scientists place instruments at locations around the globe to measure the amount of ultraviolet radiation getting through the atmosphere at each site. From these measurements, they calculate the concentration of ozone in the atmosphere above that location. These data, although useful in learning about ozone, are not able to provide an adequate picture of global ozone concentrations.

Contrary to the image created by the term "ozone layer," the amount and distribution of ozone molecules in the stratosphere vary greatly over the globe. Ozone molecules drift and swirl around the stratosphere in changing concentrations—much as clouds do in the satellite weather pictures you see on television news. Therefore, scientists observing ozone fluctuations over just one spot could not be confident that a change in local ozone levels meant an alteration in global ozone levels, or simply a fluctuation in the concentration over that particular spot. Satellites have given scientists the ability to overcome this problem because they provide a picture of what is happening simultaneously over the entire Earth.

Scientists now are confident that ozone is being depleted worldwide—partly due to human activities. However, scientists still need to determine *how much* of the loss is the result of human activity, and how much is the result of fluctuations in natural cycles.

Predicting Ozone Levels

If scientists can separate the human and natural

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causes of ozone depletion, they can formulate improved models for predicting ozone levels. The predictions of early models already have been used by policy makers to determine what can be done to reduce the ozone depletion caused by humans. For example, faced with the strong possibility that CFCs could cause serious damage to the ozone layer, policy makers from around the world in 1987 signed a treaty known as the *Montreal Protocol*. This treaty set strict limits on the production and use of CFCs. By 1990, the growing amount of scientific evidence against CFCs prompted diplomats to strengthen the requirements of the Montreal Protocol. The revised treaty called for a complete phaseout of CFCs by the year 2000.

However, scientists agree that much remains to be learned about the interactions that affect ozone. To create accurate models, scientists must study simultaneously all of the factors affecting ozone creation and destruction. Moreover, they must study these factors from space continuously, over many years, and over the entire globe. NASA's Earth Observing System (EOS) will allow scientists to study ozone in just this way. The EOS series of satellites will carry a sophisticated group of instruments that will measure the interactions of the atmosphere that affect ozone. Building on more than 20 years of data gathered by previous NASA missions, these measurements will increase dramatically our knowledge of the chemistry and dynamics of the upper atmosphere and our understanding of how human activities are affecting Earth's protective ozone layer.

For more information write to :
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Mission to Planet Earth
Selected Missions to Study Ozone

Mission	Launch	Scientific Objectives
Nimbus Series: Monitor of Solar Ultraviolet Energy (MUSE) Backscatter Ultraviolet Spectrometer (BUV) Solar Backscatter Ultraviolet/Total Ozone Mapping Spectrometer (SBUV/TOMS)	1969-1978	Monitored solar energy controlling stratospheric ozone Mapped total global ozone and the vertical distribution of ozone in the stratosphere
Stratospheric Aerosol and Gas Experiment (SAGE II) /Earth Radiation Budget Satellite (ERBS)	1984	Maps ozone at all latitudes
NOAA-9, 11, I, K, M (SBUV/2)	1984-1998	Maps total ozone and the vertical distribution of ozone in the stratosphere
Shuttle Solar Backscatter Ultraviolet (SSBUV)	1989-1995	In-orbit calibration checks of satellite instruments
Total Ozone Mapping Spectrometer (TOMS) /Meteor-3 (Russian) /Earth Probes (U.S.) /ADEOS (Japan)	1991-1998	Daily high-resolution global mapping of total ozone (TOMS first was flown on Nimbus-7 in 1978.)
Upper Atmosphere Research Satellite (UARS)	1991	Monitors solar energy, upper atmospheric chemistry and dynamics
ATLAS/STS Payloads	1992-1995	Monitors solar energy, upper atmospheric chemistry and dynamics
Earth Observing System (EOS)	1998-2012	Comprehensive investigations of ozone processes, particularly with data from the EOS-Chemistry missions beginning in 2002

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Ozone, Climate, and Global Atmospheric Change

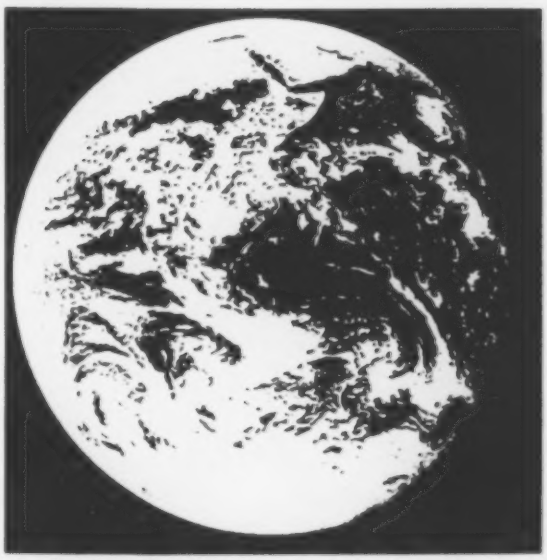
JOEL S. LEVINE

The delicate balance of the gases that make up our atmosphere allows life to exist on Earth. Ozone depletion and global warming are related to changes in the concentrations of these gases. To solve global atmospheric problems, we need to understand the composition and chemistry of the Earth's atmosphere and the impact of human activities on them.

The Composition of the Earth's Atmosphere

The atmosphere of our planet contains several hundred different gases of diverse origins. However, about 99.96 percent of the total mass of the atmosphere is due to the presence of three major permanent constituents: nitrogen (N_2), 78.08 percent by volume; oxygen (O_2), 20.95 percent by volume; and argon (Ar), 0.93 percent by volume. Water vapor (H_2O), an atmospheric gas with a variable concentration, ranges by volume from a small fraction of a percent up to 1 or 2 percent.

The remaining constituents of the atmosphere are trace gases whose atmospheric abundances are too low to be measured by percent (a unit of measure that is the same as parts per hundred by volume). Instead, the concentrations of the trace gases are measured in terms of *mixing ratio*—the number of molecules of the trace gas divided by the number of total atmospheric molecules (nitrogen, oxygen, argon, and all the others) in one cubic centimeter of air. Trace gases such as ozone (O_3), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and halons (brominated CFCs) are measured in parts per million by volume (ppmv), parts per billion by volume (ppbv), or parts per trillion by volume (pptv). The concentrations of the major and



NASA

The Earth photographed by the Apollo 17 astronauts in December 1972 during the final manned mission to the moon. The Antarctic ice cap is brightly illuminated. Two of the key elements that control the climate appear in the photograph: clouds and the oceans.

JOEL S. LEVINE, Senior Research Scientist, Theoretical Studies Branch, Atmospheric Sciences Division, NASA Langley Research Center, Hampton, Virginia, was selected as Virginia's Outstanding Scientist for 1987. Also a recipient of the NASA Medal for Exceptional Scientific Achievement, Dr. Levine wrote the lead article in the February-March 1981 issue of *Science Activities*, entitled "The Early Atmosphere: A New Picture." In addition, Dr. Levine edited and contributed to *The Photochemistry of Atmospheres: Earth, the Other Planets, and Comets*, published by Academic Press, Inc., in 1985, and *Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications*, published by the MIT Press, Inc., in 1991.

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Table 1. Major and Selected Trace Gases in the Atmosphere

Gases	Concentration
Nitrogen (N_2)	78.08 percent by volume
Oxygen (O_2)	20.95 percent by volume
Argon (Ar)	0.93 percent by volume
Water vapor (H_2O)	0 to 1 or 2 percent by volume
Carbon dioxide (CO_2)	350 ppmv
Ozone (O_3)	
In troposphere	0.02 to 0.1 ppmv
In stratosphere	0.1 to 10 ppmv
Methane (CH_4)	1.7 ppmv
Nitrous oxide (N_2O)	0.31 ppmv
CFC-12 (CF_2Cl_2)	0.5 ppbv
CFC-11 ($CFCl_3$)	0.3 ppbv
Halon-1301 ($CBrF_3$)	2.0 pptv
Halon-1211 ($CBrClF_2$)	1.7 pptv
Hydroxyl (OH)	
In troposphere	0.015 pptv
In stratosphere	0.02 pptv to 0.3 ppbv
Nitric Oxide (NO)	
In troposphere	0 to 1 ppbv
In stratosphere	Up to 0.02 ppmv

Note: The concentrations of atmospheric gases are given in either percentage by volume (which is the same as parts per hundred by volume), parts per million by volume (ppmv), parts per billion by volume (ppbv), or parts per trillion by volume (pptv).

selected trace gases in the atmosphere are summarized in table 1.

It is an interesting and somewhat ironic fact that the chemistry of the atmosphere and the temperature of our planet are not controlled by the major gases, but rather by the trace gases. There is growing evidence that the trace-gas composition of the atmosphere is changing. The environmentally significant trace gases are affected by both natural and human-produced gases. Among these gases are the chlorofluorocarbons, human-made gases such as CFC-11 and CFC-12 that are used as propellents in aerosol spray cans; halons used in fire extinguishers; and carbon dioxide, nitrous oxide, and methane, which are produced by the burning of fossil fuels and living and dead biomass and by the metabolic processes of microorganisms in the soil, wetlands, and oceans of our planet.

The Origin of Atmospheric Ozone

The development of the atmospheric ozone layer had a very significant impact on the evolution of life on our planet. Throughout most of its 4.6 billion-year history, there was an insufficient level of ozone in the atmosphere to shield the Earth's surface from the biologically lethal ultraviolet radiation (electromagnetic radiation between 200 and 300 nanometers) emitted by the Sun. Before the development of the atmospheric ozone layer, life was restricted to the ocean depths where several meters of seawater absorbed the solar ultraviolet radiation and offered protection to the earliest forms of life on our planet.

About 600 million years ago, oxygen built up in the atmosphere to about 10 percent of its present atmospheric level as a result of photosynthetic activity. At this point, ozone, which is chemically formed from oxygen, reached sufficient levels in the atmosphere to effectively absorb incoming solar ultraviolet radiation, and, for the first time, living organisms could leave the safety of the ocean and live on land.

Ozone (O_3), composed of three oxygen atoms via atmospheric photochemical and chemical reactions, is a trace atmospheric gas. About 90 percent of the total atmospheric content of ozone is located in a layer between about 15 and 50 kilometers above the Earth's surface in the atmospheric region known as the stratosphere (see figure 1).

Changes in the Ozone Layer

The Antarctic Ozone Hole

Recent ground-based, aircraft, and satellite measurements have indicated an alarming trend in the level of ozone in the stratosphere over the Antarctic. These measurements indicate that, for more

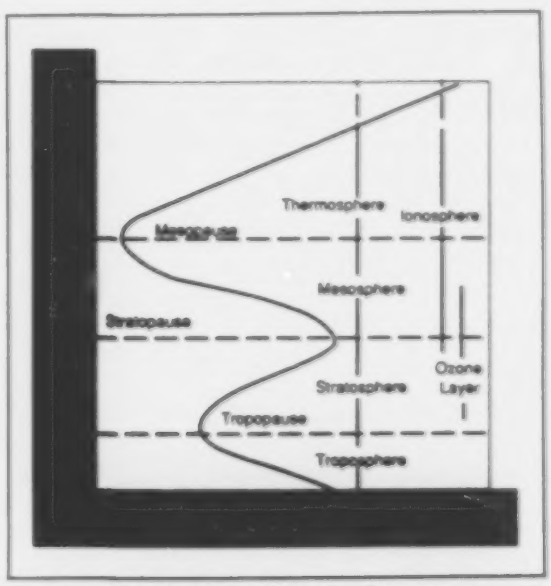

Figure 1. The structure of the Earth's atmosphere illustrating the various regions. Each region is defined by its temperature gradient. (Earth Systems Sciences Committee, NASA, 1988)

than a decade, during a specific period each year, the levels of ozone in the stratosphere have decreased by more than 50 percent. The so-called "hole" in the ozone layer is produced each year during a 4- to 6-week period, beginning in late September, which is the start of spring in the Southern Hemisphere. The area of the Antarctic ozone hole, about the size of the continental United States, has grown larger each year during this period.

Four to six weeks after the first appearance of the Antarctic ozone hole, ozone from the Southern Hemisphere mid-latitudes is transported to the South Pole by the general circulation patterns of the atmosphere and replenishes the missing gas. Then the following spring the hole reappears.

Global Changes in Stratospheric Ozone

Is there evidence for stratospheric ozone depletion outside of the Antarctic region? The Ozone Trends Panel, formed by NASA in October 1986, in collaboration with the National Oceanic and Atmospheric Administration, the Federal Aviation Administration, the World Meterological Organization, and the United Nations Environment Program has reanalyzed and reassessed the data on ozone abundances collected by the 30-year-old network of ground-based Dobson spectrophotometers concentrated in the Northern Hemisphere and by satellite instruments operating since the late 1970s.

In March 1988, the panel reported their findings: global levels of stratospheric ozone had fallen several percentage points between 1969 and 1986. The panel concluded that between 30°N latitude and 64°N latitude, from 1969 to 1986, stratospheric ozone decreased between 1.7 and 3.0 percent. The larger decreases occurred at the high latitudes in winter; the smaller drops occurred in summer.

There is other evidence to suggest that concentrations of ozone in the troposphere (the lowest atmospheric layer that extends from the surface to the beginning of the stratosphere and contains the remaining 10 percent of atmospheric ozone) have been increasing by about 1 percent per year over the past 20 years. This means that the decreases in stratospheric ozone probably exceed those for the total column content, which is the sum of tropospheric and stratospheric ozone.

What Is Destroying the Ozone?

The Ozone Trends Panel attributed the observed decreases in stratospheric ozone to increasing atmospheric levels of chlorofluorocarbons (see figure 2). The chlorofluorocarbons, Freon-11 ($CFCl_3$) and Freon-12 (CF_2Cl_2), are usually referred to as CFC-11 and CFC-12, respectively.

The major source of atmospheric CFC-11 and CFC-12 is the aerosol spray can, which uses these chemically inert gases as propellents. CFCs are also used as refrigerants in home and automobile air conditioners and in the manufacturing of closed-cell and open-cell foams.

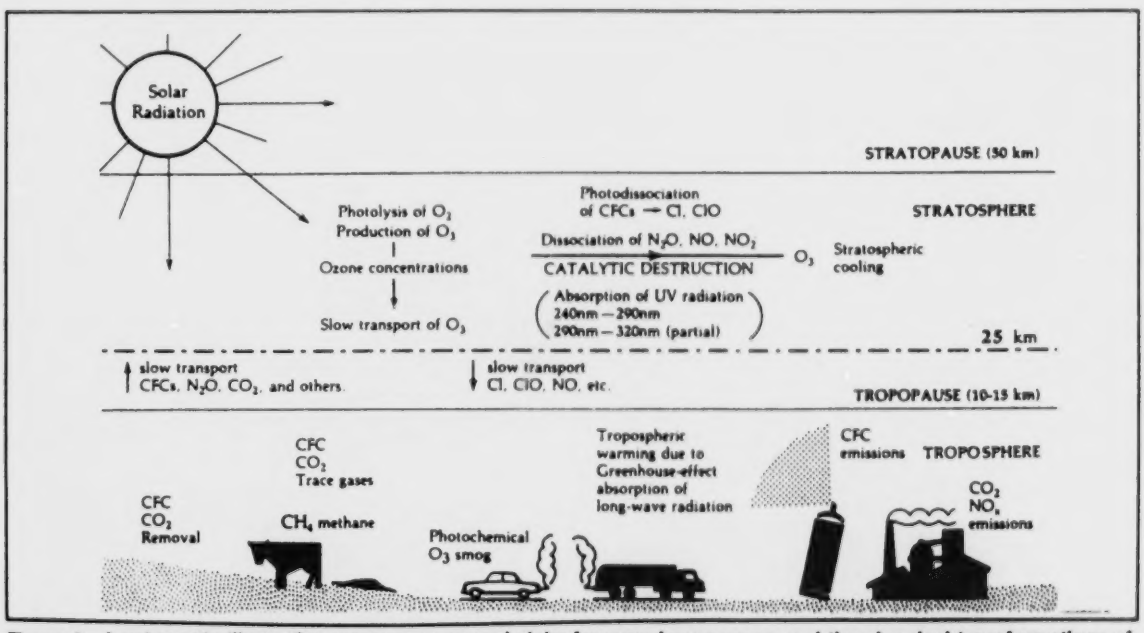

Figure 2. A schematic illustrating some sources and sinks for greenhouse gases and the chemical transformations of these gases in the troposphere and stratosphere. (International Geosphere-Biosphere Programme, 1990)

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Additional trace gases that destroy ozone in the stratosphere by chemical reactions include bromine (Br), nitric oxide (NO) and the hydroxyl radical (OH). Methane reactions produce the water vapor that releases the hydroxyl radical in the stratosphere.

Ozone Depletion Caused by Chlorine and Bromine

The cause of the Antarctic ozone hole is now believed to be the chlorine and bromine originally released from the CFCs and halons, or brominated CFCs. These two elements are released into the atmosphere through a series of reactions.

Chlorine atoms are liberated in the stratosphere by the action of solar radiation on CFC-11 and CFC-12 molecules, the only significant source of chlorine atoms in the stratosphere. The ice clouds that form in the dry, frigid, isolated Antarctic stratosphere greatly facilitate the chemical reactions that free chlorine atoms from the reservoir compounds, where they reside after being released from the CFCs. Then the chlorine is readily available to chemically destroy ozone in the Antarctic stratosphere after the long, cold Antarctic winter.

Atmospheric levels of CFC-11 and CFC-12 are about 0.3 ppbv and 0.5 ppbv, respectively. The levels of each of these gases is increasing at a rate of about 5 percent per year. The atmospheric lifetimes (the time before the gas is destroyed or lost to the atmosphere) of CFC-11 and CFC-12 are about 65 and 130 years, respectively.

After warnings about stratospheric ozone depletion caused by CFCs, the United States banned the use of these gases in aerosol spray cans in 1978. Unfortunately, the rest of the world did not. However, in September 1987, representatives from more than thirty nations signed the Montreal Protocol, which froze CFC production rates at 1986 levels after 1989 and will cut them in half by 1999. In 1990, in London, the provisions of the original 1987 Montreal Protocol were strengthened by the participating countries. This will lead to a more rapid phaseout of aerosol spray CFCs and halons. Nevertheless, because of their very long atmospheric lifetimes, the impact of the CFCs and halons already released will still be felt for many years following their phaseout.

Also implicated in the springtime chemical destruction of ozone over the Antarctic is bromine (Br). Human-produced sources of bromine include the halons, or brominated CFCs, such as bromotrifluoromethane (Halon-1301: $CBrF_3$) and bromochlorodifluoromethane (Halon-1211: $CBrClF_2$). Bromine monoxide (BrO), produced from Halon-1301 and Halon-1211, reacts with chlorine monoxide (ClO), produced from CFCs, to release bromine (Br) and chlorine (Cl), both of which destroy ozone in the stratosphere.

Most halons are used as fire-extinguishing agents. The atmospheric concentrations of Halon-1301 and 1211 are only 2 pptv and 1.7 pptv, respectively. However, their atmospheric levels are increasing at rates of 15 percent and 12 percent per year, respectively. The atmospheric lifetime of Halon-1301 is about 110 years; that of Halon-1211, about 25 years.

Ozone Depletion Caused by Nitric Oxide

Molecules of nitric oxide also destroy stratospheric ozone. These molecules are produced by the chemical transformation of nitrous oxide in the stratosphere. Most nitrous oxide is produced by bacteria in natural and fertilized soils during the processes of nitrification and denitrification.

The surface concentration of nitrous oxide is about 0.31 ppmv. Measurements indicate that nitrous oxide is increasing about 0.2 to 0.3 percent per year. The atmospheric lifetime of nitrous oxide is about 150 years.

Effects of Ozone Depletion

Calculations indicate that for each one percent decrease in atmospheric ozone, the amount of solar ultraviolet radiation reaching the ground will increase by 2 percent. It is estimated that a 2 percent increase in solar ultraviolet radiation could increase future skin cancer cases by 3 to 6 percent each year. There are presently about 500,000 cases of skin cancer diagnosed each year in the United States.

It has also been suggested that solar ultraviolet radiation can damage the human immune system, cause billion of dollars worth of crop damage, and adversely affect plankton in the ocean, the base of the marine food chain.

What Is the Greenhouse Effect?

Another change in the atmosphere that is affecting our climate is the increasing concentrations of greenhouse gases. This buildup of greenhouse gases results in a greater warming of the Earth's surface.

Greenhouse gases have the ability to absorb, or trap, upward-moving infrared radiation, heat energy, emitted by the Earth's surface (see figure 3). The greenhouse gases quickly reemit, or release, the absorbed heat energy with approximately 50 percent of the reemitted energy directed back toward the Earth's surface. This heat energy would have been lost to space if it had not been trapped by greenhouse gases.

Ozone, Methane, Nitrous Oxide, and the CFCs as Greenhouse Gases

While ozone in the stratosphere is decreasing, measurements indicate that ozone, as well as other trace gases, is increasing in the troposphere. It is ironic that, while ozone in the stratosphere is bene-

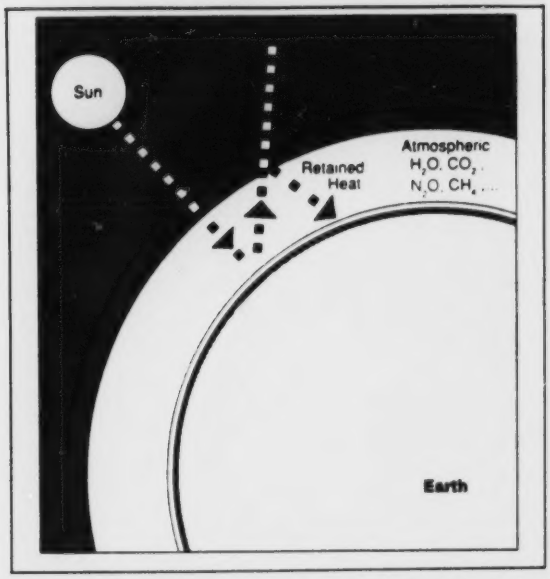

Figure 3. The greenhouse effect results from the fact that the atmosphere is transparent to incoming solar radiation, but absorbs and reemits infrared radiation emitted at the surface. This effect is made stronger by increasing concentrations of water vapor, carbon dioxide, nitrous oxide, and methane. (Earth Systems Sciences Committee, NASA, 1988)

ficial to human health and survival, tropospheric ozone in high concentrations is a pollutant that is harmful to human, animal, and plant life.

In the troposphere, ozone is chemically formed from the combustion products of fossil fuel burning, including automobile exhaust gases, and the combustion products of biomass burning. Increasing trace gases in the troposphere, in addition to ozone, include carbon dioxide, methane, nitrous oxide, and the chlorofluorocarbons CFC-11 and CFC-12 (see figure 4). All six of these gases are greenhouse gases.

Water Vapor as a Greenhouse Gas

Water vapor is the most important atmospheric greenhouse gas. The water vapor concentration of the troposphere, where almost all of the water vapor in the atmosphere is located, is controlled by atmospheric temperature and the evaporation and condensation cycle. At present, atmospheric water vapor concentrations do not appear to be changing as a result of human activities.

Carbon Dioxide as a Greenhouse Gas

After water vapor, carbon dioxide is the most important greenhouse gas. The surface concentration of carbon dioxide is about 350 ppmv. Measurements indicate that carbon dioxide is increasing by about 0.5 percent per year.

Carbon dioxide is chemically inert in the atmosphere. Hence, there are no significant atmospheric reactions that form sinks, or repositories, for carbon dioxide. The sinks for carbon dioxide include uptake and incorporation in the living biosphere during photosynthetic activity, dissolution in the ocean with the subsequent formation of carbonate rocks (limestone, calcite, dolomite, etc.) and the build-up of the gas in the atmosphere.

Carbon dioxide is produced by biological respiration on land and in the ocean and by the burning of fossil fuels and living and dead biomass. It is interesting to note that the bulk of the burning of fossil fuels occurs in the industrialized or developed countries, while almost all of the biomass burning takes place in the Third World developing countries of South America, Africa, and Asia.

The Double Whammy of Deforestation

Deforestation by burning, a widespread practice in the world's tropical rain forests, adversely impacts the trace-gas composition of the atmosphere in two different ways. First, the burning of the tropical forests produces large amounts of carbon dioxide, carbon monoxide (CO), methane, and other trace gases that are the combustion products of biomass burning. Second, the tropical forest is an important sink, or repository, for carbon dioxide. Atmospheric carbon dioxide is incorporated into the living biomass via the process of photosynthesis, which in turn produces atmospheric oxygen.

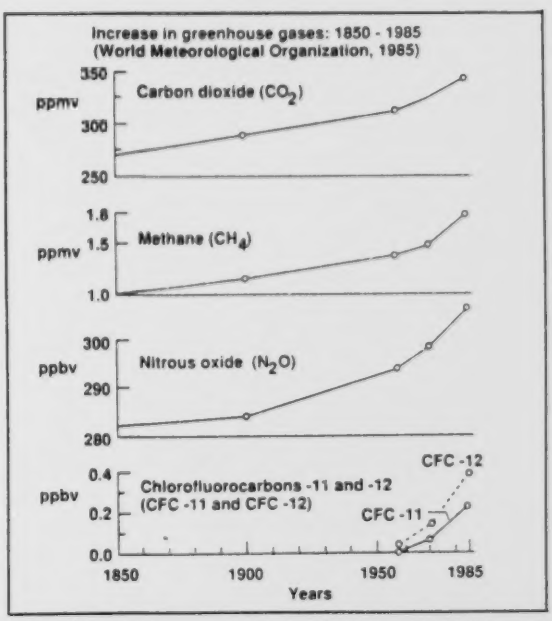

Figure 4. The increase in atmospheric concentrations of greenhouse gases from 1850 to 1985. (World Meteorological Organization, 1985)

Ozone Update

In October 1991, the most recent assessment of stratospheric ozone, entitled the Scientific Assessment of Stratospheric Ozone—1991, was finalized. The study was coordinated by the United Nations Environmental Program (UNEP), the World Meteorological Organization (WMO), the United Kingdom Department of the Environment, the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). The report of the results and implications of this study is just now coming out. Because of the timeliness of this new scientific assessment and its relevance to this article, I have excerpted the following major points from the executive summary.

EXCERPTS FROM THE EXECUTIVE SUMMARY

Latest Assessments

Global Ozone Decreases: Ground-based and satellite observations continue to show decreases of total column ozone in winter in the northern hemisphere. For the first time, there is evidence of significant decreases in spring and summer in both the northern and southern hemispheres at middle and high latitudes, as well as in the southern winter. No trends in ozone have been observed in the tropics. These downward trends were larger during the 1980s than in the 1970s. The observed ozone decreases have occurred predominantly in the lower stratosphere.

Polar Ozone: Strong Antarctic ozone holes have continued to occur and, in four of the past five years, have been deep and extensive in area. This contrasts to the situation in the mid-1980s, where the depth and area of the ozone hole exhibited a quasi-biennial modulation. Large increases in surface ultraviolet radiation have been observed in Antarctica during periods of low ozone. While no extensive ozone losses have occurred in the Arctic comparable to those observed in the Antarctic, localized Arctic ozone losses have been observed in winter concurrent with observations of elevated levels of reactive chlorine.

Ozone and Industrial Halocarbons: Recent laboratory research and re-interpretation of field measurements have strengthened the evidence that the Antarctic ozone hole is primarily due to chlorine- and bromine-containing chemicals. In addition, the weight of evidence suggests that the observed middle- and high-latitude ozone losses are largely due to chlorine and bromine. Therefore, as the atmospheric abundances of chlorine and bromine increase in the future, significant additional losses of ozone are expected at middle latitudes and in the Arctic.

Implications for Policy Formulations

The findings and conclusions of the research of the past few years may have several major implications on policy decisions regarding human-influenced substances that lead to stratospheric ozone depletions and to changes in the radiative forcing of the climate system.

Continued Global Ozone Losses: Even if the control measures of the amended Montreal Protocol (London, 1990) were to be implemented by all nations, the current abundance of stratospheric chlorine (3.3-3.5 ppbv) is estimated to increase during the next several years, reaching a peak of about 4.1 ppbv around the turn of the century. With these increases, the additional middle-latitude ozone losses during the 1990s are expected to be comparable to those observed during the 1980s, and there is the possibility of incurring wide-spread losses in the Arctic. Reducing these expected ozone losses requires further limitations on the emissions of chlorine- and bromine-containing compounds.

Approaches to Lowering Global Risks: Lowering the peak and hastening the subsequent decline of chlorine and bromine levels can be accomplished in a variety of ways, including an accelerated phase-out of controlled halocarbons.

Elimination of the Antarctic Ozone Hole: If all nations were to fully comply with the phase-out schedule of the amended Montreal Protocol, and if all uses of hydrochlorofluorocarbons (HCFs) [hydrogen-containing CFCs that are more chemically active and hence shorter-lived than other CFCs] were discontinued, then it is estimated that stratospheric chlorine abundances would return to 2 ppbv sometime between the middle and the end of the next century. This is the level at which the antarctic ozone hole appeared in the late 1970s and hence, is the level that is considered necessary (assuming other conditions are constant, including bromine loading) to eliminate the ozone hole. Such levels could never have been reached under the provisions of the original Protocol (Montreal, 1987).

The statistics on the loss of the world's tropical rain forests are staggering. Less than 60 percent of the originally forested land in the tropics remains. Most of the destruction of the tropical forests by burning has taken place in the last 30 years. Deforestation rates are about 28 million acres a year, or about 50 acres a minute. At that rate, what remains of the world's tropical rain forests could be reduced by half in less than 50 years and be totally gone within 100 years.

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The amount of carbon dioxide and other trace gases produced during biomass burning on a global scale is not precisely known. For one thing, there is very little information available on the type and concentration of gases produced by biomass burning in the rest of the world's very diverse ecosystems, such as mid-latitude and northern latitude forests and wetlands. A recent report by the National Academy of Sciences indicates that biomass burning may cover as much as 5 percent of the total land area of our planet each year.

Methane as a Greenhouse Gas and Ozone Depleter

Another carbon-containing greenhouse gas is methane. The surface concentration of methane is

about 1.7 ppmv. Atmospheric measurements indicate that methane is increasing about 1.0 percent per year. Most methane is produced by microorganisms in anaerobic, oxygen-deficient, environments. The major global sources of methane are wetlands, swamps, and rice paddies (all strongly anaerobic environments). Other major sources of methane are enteric fermentation in cattle, natural gas and mining losses, and biomass burning.

Unlike carbon dioxide, methane is chemically active in both the troposphere and stratosphere. In the troposphere, the reaction between methane and the hydroxyl radical (OH) leads to the chemical production of ozone, which is a greenhouse gas.

In the stratosphere, methane is an important source of water vapor. The hydroxyl radical formed from the chemical transformation of water vapor leads to the destruction of stratospheric ozone. On the other hand, methane reactions also decrease the effectiveness of chlorine and nitric oxide in the destruction of stratospheric ozone.

Possible Effects of Greenhouse Gases

Theoretical calculations of climate change are often made by using computer models that project the effect of the increasing concentrations of greenhouse gases. It should be emphasized that the climate is a very complex and not completely understood system that is controlled and regulated by incoming solar radiation, outgoing Earth-emitted radiation, clouds, the oceans, and the evaporation and precipitation cycle, as well as by atmospheric greenhouse gases.

Temperature Increases Caused by Greenhouse Gases

Theoretical climate calculations indicate that a doubling of atmospheric carbon dioxide could increase the global average equilibrium surface temperature of our planet between 1.5°C and 4.5°C and that a doubling of atmospheric methane could increase the equilibrium surface temperature of the Earth between 0.2°C and 0.4°C. Similar calculations indicate that a doubling of atmospheric nitrous oxide could increase the equilibrium surface temperature between 0.3°C and 0.4°C and an increase of CFC-11 and CFC-12 to 2 ppbv each could increase the equilibrium surface temperature by about 0.3°C for each gas. A 50 percent increase of ozone in the troposphere could lead to an increase in surface temperature of about 0.3°C.

These calculations indicate that as a result of the increasing atmospheric levels of the greenhouse gases, the mean global temperature of our planet will increase by at least 1°C per decade.

Polar Warming and Rising Sea Levels

According to these theoretical calculations, a surface temperature increase of only 1°C or 2°C at midlatitudes could result in a heating of the polar regions several times greater. This would happen because the melting of polar ice and snow would expose the underlying land or ocean, which do not reflect the Sun's rays as well as highly reflective ice and snow. The greater absorption of solar radiation would amplify the temperature increase in these ice- and snow-covered regions.

Because heating results in both the thermal expansion of seawater and the melting of polar ice and snow, a temperature increase could result in a rise of the world's oceans by a foot or more by the year 2050. Such a rise in sea level would threaten the homes of tens of millions of people worldwide.

Further Information

This is a general presentation that can be used as a background to prepare units for all levels of students. If you need a more detailed description of the chemical reactions involved in ozone destruction, write to *Science Activities* for a photocopy of "The Chemistry of Ozone Destruction," an unpublished appendix to this article.

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PAPER

Atmospheric Chemistry: Causes and Effects

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ABSTRACT

Changes in the composition of the atmosphere may signal changes in our climate. Human activities are increasing the concentrations of gases with a warming potential contributing to the natural greenhouse effect. The measured loss of the ozone shield, particularly around the polar regions, is also caused by man's activities. While we are making progress in reducing the input of ozone depleting chemicals through an international agreement, the Montreal Protocol, we will see little effect on the atmosphere before the end of the century. Man's short-sighted activities cannot continue without resulting in environmental damage that could have implications far beyond those we have considered here.

INTRODUCTION

The first Earth Day took place, as you may remember, in April 1970. Both of my children and my wife were very interested in Earth Day, and as a laboratory scientist, I began to wonder if there were some way that I could react to this. Was there a way that I could use what I knew and apply it to some environmental problem?

A meeting later in 1970 on environmental applications of radioactivity led to an invitation to attend a Chemist-Meteorologist Workshop held in Fort Lauderdale, Florida, in January 1972 under the sponsorship of the Atomic Energy commission. There I heard the results of an interesting experiment that was being carried on by Jim Lovelock, a freelance scientist in England. Lovelock had invented a technique called electron-capture gas chromatography. Basically, this is a very sensitive technique for detecting certain molecules in extremely low concentrations, in particular, molecules that capture electrons, and these turn out to be mostly molecules that contain chlorine. Lovelock had set up the apparatus at his home in Western Ireland to see if he could measure any trace species in the Irish atmosphere.

When the wind blew from London he could see that there were several compounds present that he could detect. Moreover, when the wind blew from the Atlantic Ocean, he was still able to detect some compounds. Subsequently, he also took measurements from a ship bound for Antarctica and found that a compound called trichlorofluoromethane, also known as Chlorofluorocarbon-11, one of the inert gases used in spray cans, was present in every air sample he took. The chlorofluorocarbons (CFCs) are often identified by the trademarks of individual companies, especially the Dupont Company's "Freon."

I began to wonder what was going to happen to this man-made compound newly introduced into the atmosphere. When my research group gets a new graduate student or a new post-doctoral fellow, I discuss with them what sorts of research they are interested in pursuing. In 1973, a new post-doctoral fellow, Dr. Mario Molina, joined my group and chose as his project to explore what was happening to trichlorofluoromethane. Later, I will discuss the progress in this study over the past fifteen years. Before I get into the specifics of the destruction of the ozone layer by chlorofluorocarbons, I want to give a general description of the atmosphere and its radiative and chemical properties.

In addition to its major components (nitrogen, oxygen, argon), our atmosphere is naturally composed of water vapor, carbon dioxide, methane, nitrous oxide, ozone, and a number of other trace species as well as a number of non-natural components developed by man, for example, chlorofluorocarbons. Our primary source of energy is the sun. The sun is very hot (6000° K at the surface) and as a result emits radiation that is mostly in the wavelength region from 400 nanometers to 700 nanometers. We describe the radiation that comes from the sun into the atmosphere in terms of the response of the human eye. We talk about the visible wavelengths from red to violet. Beyond the red is the infrared and ultraviolet is on the far side of the violet. The wavelength of the individual radiation increases and the energy decreases as one moves from ultraviolet (short wavelength) to infrared (longer wavelength). Ultraviolet (UV) radiation can cause sunburn, while the much less energetic infrared (IR) radiation gives warmth (Figure 1).

While some solar radiation is reflected back into space by clouds, most of it is absorbed by the land, the oceans, or the atmosphere. An equivalent amount of energy must escape from the earth to maintain thermal balance, but because of the much lower temperature (300° K versus 6000° K for the sun), terrestrial radiation is emitted in the infrared. However, some of this IR radiation is absorbed by water vapor, carbon dioxide, ozone, and CFCs in the atmosphere. The earth warms up because of this trapping of IR radiation by atmospheric gases, and this natural process has been termed the greenhouse effect (Figure 2). However, an increase in any of the absorbing gases increases the amount of

heat from the earth that is prevented from escaping to space. The earth must then warm up still more to push IR radiation out at those wavelengths *not* absorbed by these gases. If the earth did not have a greenhouse effect then it would be approximately 33 degrees centigrade cooler than it is and not be conducive to life as we know it; for example, all water would be frozen. At the other extreme is Venus where the atmosphere has a much higher carbon dioxide content and retains much more of the radiant heat and where the resulting surface temperature is about 700° K.

In our atmosphere, one molecule of CCl_2F_2 (the chemical description of CFC-12 before switching to the technological term) is 10,000 times more effective at trapping heat than one additional molecule of carbon dioxide. Carbon dioxide is increasing at a rate of about 1,500 parts per billion by volume (ppbv) yearly (versus 0.02 ppbv for CFC-12) and still accounts for half or more of the incremental greenhouse increase. The larger heat trapping ability of CFCs is important to remember because CFCs also play a very important role in the reduction of the ozone layer. Both of these impacts are significant, especially when discussing the establishment of domestic and international laws and policies to reduce global warming and destruction of the ozone layer.

One other important point can be made about scientific measurements and greenhouse gases. The longest running data set related to greenhouse gases and potential global warming is that of carbon dioxide taken by David Keeling (Scripps Institution of Oceanography, University of California at San Diego) at the Mauna Loa Observatory in Hawaii (see Kellogg's Figure 1 in this issue). The familiar saw-toothed graph clearly shows a substantial increase in carbon dioxide measurements in the atmosphere from the beginning of the record in 1958 (315 ppm) to the present (355 ppm). The saw-toothed pattern is reflective of the growth in flora that occurs in the spring and summer in the Northern Hemisphere where the leaves act as a carbon sink. When the leaves fall in the winter, the trees and other plants no longer act to take up and store additional carbon dioxide and allow the atmospheric levels of CO_2 to rise again. The Mauna Loa record was a crucial piece in the identification of changes in the atmospheric concentration of greenhouse gases. That graph is now nearly synonymous with the concept of global change.

CFC CHEMISTRY AND OZONE DEPLETION

Trichlorofluoromethane is transparent, insoluble in water, and relatively unreactive.

FIGURE 1. Solar radiation upon the earth's atmosphere. Visible radiation (400 to 700 nm) penetrates to the surface as does energetic ultraviolet radiation with wavelengths between 320 to 400 nm. Very high energy ultraviolet radiation is absorbed by (*a*) molecular O_2 to create the ozone layer in the stratosphere; and (*b*) ozone to create the stratosphere itself. Little infrared radiation is given off by the sun, but all of the earth radiation falls in the long wavelength infrared region.

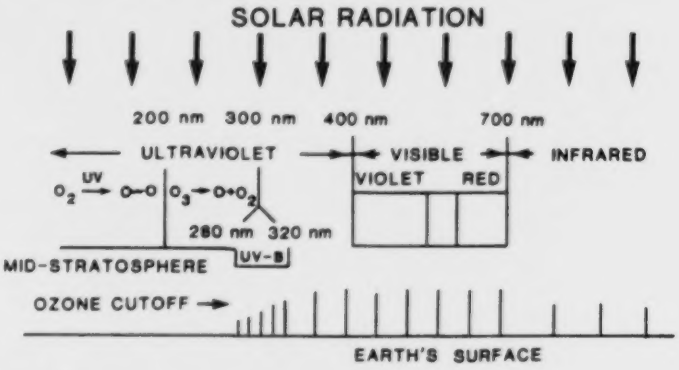
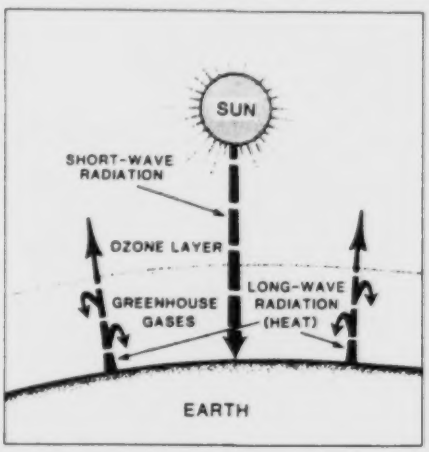


FIGURE 2. The greenhouse effect. Visible radiation from the sun reaches the earth's surface unhindered, but the outgoing long-wave radiation is partially trapped, or retained, by carbon dioxide and other gases in the atmosphere.



Nothing happens to it on the time scale of a year or so. But what can happen to it if it is left long enough?

Red light penetrates through the atmosphere better than blue light. The light near sunset is coming through a very long atmospheric path, and the blue light is scattered out, leaving a very red sun. Because the blue wavelengths from the sun are scattered by the atmosphere, the sky appears blue. These effects remind us that radiation of different wavelengths has quite varying effects in the atmosphere.

Infrared radiation does not carry enough energy to cause most molecules to decompose. Violet or ultraviolet radiation from the sun has enough energy to cause some of the trichlorofluoromethane molecules to decompose but only if this UV reaches the CFC molecule.

Most (98 percent) of the energy from the sun arrives in the visible wavelength with 2 percent in the ultraviolet. However, this ultraviolet radiation makes important changes in the gases in the atmosphere. Ultraviolet radiation can split molecular oxygen (O_2) into two oxygen atoms. The usual fate of an oxygen atom is to find another molecule of oxygen and form triatomic oxygen, or "ozone." It is, therefore, molecular oxygen in the presence of ultraviolet radiation from the sun that creates ozone (Figure 3). As soon as there is ozone, there is another molecule that can absorb ultraviolet radiation, splitting it into an oxygen atom and an O_2 or oxygen molecule. This newly-released atom of oxygen usually finds another O_2 and reforms the ozone.

Ultraviolet radiation is always making ozone and it is also decomposing ozone, and in the process the UV energy is converted into heat. This heat source creates the stratosphere (Figure 3), a region in which the temperature increases as altitude increases. Thus, the ozone "layer" produces the stratosphere and, at the same time, prevents much of the ultraviolet radiation from the sun from reaching the surface of the earth.

Molina and I developed the theory that if a molecule of trichlorofluoromethane was released in the lower atmosphere (the troposphere, where it gets colder with altitude and where we live and breathe) and it could get high enough (into the stratosphere), it could absorb ultraviolet light. Trichlorofluoromethane would then absorb solar UV radiation in the stratosphere and be split apart to produce free chlorine atoms. The stratosphere, then, because of the high energy ultraviolet radiation from the sun, would have the ability of converting this CFC molecule to chlorine atoms. So, what is going to happen to the chlorine atoms?

That question turns an interesting scientific problem into an environmental issue. A chlorine atom (Cl) reacts with the ozone (O_3) to give off a species called chlorine oxide (ClO). Chlorine oxide then reacts with oxygen atoms (O) to yield atomic chlorine again. The overall result of this sequence of two reactions is that an ozone molecule (O_3) and an oxygen atom (O) (which otherwise would have formed an ozone [O_3]) have been converted back to molecular oxygen (O_2). The chlorine atom is still there, ready to repeat this process (Figure 4).

This is a chain reaction. It is catalytic because the chlorine causes the ozone to be converted to oxygen, but the chlorine is not used up in the process. In fact, the two reactions require only one minute in the stratosphere. A chlorine atom is on the loose, destroying ozone at the rate of one molecule per minute. The chlorine atoms eventually make their way back through the ozone layer toward ultimate deposition in rainfall as hydrochloric acid (HCl). The roundtrip for the chlorine atom from release in the stratosphere to final rainout requires a year or two, during which time each chlorine atom destroys approximately 100,000 molecules of ozone. When man is emitting nearly one million tons of CFCs on a yearly basis, that translates into an ozone loss about 10^5 times larger.

FIGURE 3. Schematic diagram for absorption of solar ultraviolet radiation by ozone with the creation of the stratosphere (temperature increase with increasing altitude).

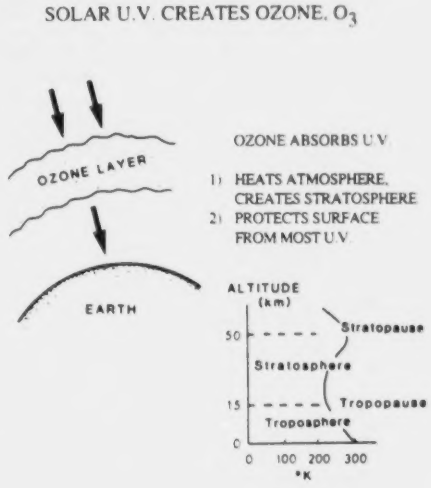
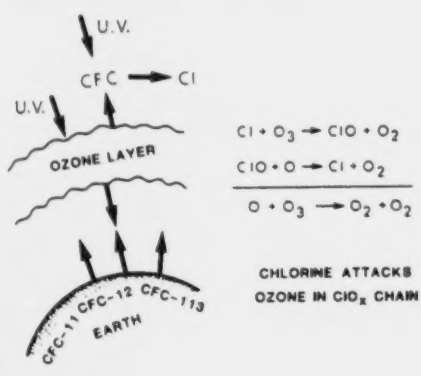


FIGURE 4. Schematic diagram for release of CFC gases at the surface, their photolysis above the ozone layer, and the chlorine chain reaction for removal of ozone.



At the time Molina and I first made our calculations and predictions, no measurements existed anywhere in the stratosphere for any chlorine containing compound. However, we had calculated the CFC concentrations to be expected at each altitude, based on laboratory studies and a simple one-dimensional atmospheric model. Through the lower atmosphere, the troposphere, we anticipated no change in the relative amounts of trichlorofluoromethane and nitrogen and oxygen. However, in the stratosphere, CFC-11 should photodissociate, decreasing in mixing ratio from 20 to 30 km and with almost none left at 35 km.

Using a technique originally devised in the nineteenth century by chemist Gay-Lussac, air samples were collected, brought back to the laboratory for measurement, and the results were compared with the predictions. The chlorofluorocarbons do get into the stratosphere, and once they are there, they disappear essentially as predicted; that is, the solar ultraviolet will break down the CFCs and begin the process of ozone destruction. As soon as it was confirmed that the CFCs do indeed reach the stratosphere and that they photodissociate, we returned to the question of potential atmospheric sinks. Do the CFCs really not react in the lower atmosphere? Careful comparison of the amounts of CFCs emitted to the atmosphere versus the amounts still remaining there confirmed that the atmospheric lifetimes were indeed very long—a century or so. No rapid tropospheric removal processes exist for these compounds. The only removal process that seems to work is ultraviolet radiation in the middle stratosphere, above the ozone layer.

Lovelock's CFC-11 measurements in 1971 showed approximately 70 parts per trillion. In the summer of 1979, we found approximately 170 parts per trillion of CFC-11 in the Northern Hemisphere, an increase by more than a factor of 2 in just eight years! From continuations of such measurements, we now know that five times as much chlorine is now in the atmosphere as there was in 1950. Most of that increase has happened since 1970, and most of it represents carbontetrachloride, methylchloroform, and the three most common chlorofluorocarbons. The atmosphere has indeed changed very rapidly as far as chlorine is concerned.

THE ANTARCTIC AND ARCTIC OZONE HOLES

The most striking change in the atmosphere in the last decade or so was found from measurements made by the British Antarctic Survey at its Halley Bay Station on the Antarctic coast. They have operated an ozone measuring instrument since 1957. All through the 1960s, ozone measurements (averaged for October—the Antarctic spring) ranged from 300 to 320 parts per billion. Then suddenly in the late 1970s, the ozone amounts began to fall off, dropping below 200 by October 1984 (Figure 5). Something drastic had happened over Antarctica. The amount of ozone there in October is now much less than twenty years ago. Some air masses at altitudes around 15 km have now been measured that show no ozone at all!

The Northern Hemisphere has lost some ozone as well (Figure 6). It is especially noticeable in the winter. There is about 6 percent less ozone in the higher latitudes of the Northern Hemisphere in winter now than in 1970. There is a loss of about 4.7 percent over the northern part of the United States and some loss in the southern part of the United States. The yearlong average change in ozone in the north temperate zone has already reached 2 or 3 percent.

We now recognize that we are losing ozone not just over the Antarctic but also over the Northern Hemisphere as well. Furthermore, extensive experiments in the polar regions have thoroughly established that the loss of ozone has been caused by chlorine chemistry, with most of the chlorine arising from decomposed CFC molecules. Subsequent expeditions have shown that the atmospheric chemistry causing the loss of the ozone in the Arctic is very similar to what occurs in the Antarctic. The circulation of the air, though, is different in the two regions.

In the Antarctic, the stratospheric air stays in the polar vortex and goes around and

FIGURE 5. Average ozone concentrations above Halley Bay, Antarctica, for the month of October, showing the sharp decline since the mid-1970s. Data of J. Farman and colleagues from the British Antarctic Survey.

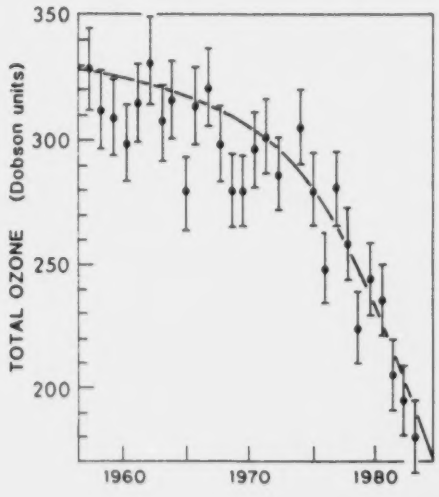
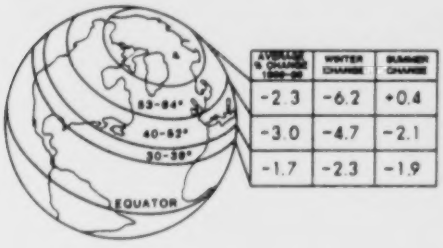


FIGURE 6. Average ozone changes for latitude bands in the Northern Hemisphere during the seventeen-year period, 1969 to 1986.



around all winter long, becoming very cold, cold enough to allow the formation of polar stratospheric clouds. These clouds trigger some special chemistry that makes the vortex and its ozone very vulnerable to the arrival of sunlight after the long polar winter. As spring arrives, major ozone losses occur within the vortex during the next several weeks. In the Northern Hemisphere, the polar vortex is not as strong and one air mass after another enters the polar darkness and soon emerges back into low sunshine. We lose a little bit of ozone from each parcel of air instead of a lot of ozone from one parcel of air. But the consequence is that we are losing ozone in both hemispheres, although more of it in the Southern Hemisphere.

OZONE LOSS: SO WHAT?

So what difference will a reduction in the ozone layer make? If less ozone exists in the upper stratosphere, less heat will be produced there because not as much UV energy will be absorbed and that will mean a change in the temperature profile because there would not be as much heat in the stratosphere. The wind patterns may also be altered because they depend on temperature gradients in the atmosphere in various regions. In effect, we could be changing the climate. With less ozone, too, more ultraviolet radiation will arrive at the surface of the earth, especially the ultraviolet B, which is known to cause biological damage in humans and other living organisms (Figure 7).

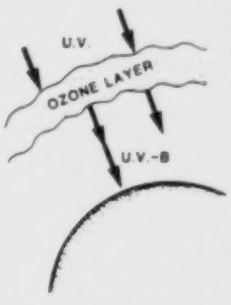
About half to two-thirds of the biological species tested turn out to be sensitive to ultraviolet B. Among the effects are stunted growth in many species of plant. The only species for which we have really good data is the human species, and we know that UV-B causes human skin cancer and cataract development. In the United States about 500,000 people a year develop skin cancer for the first time. Malignant melanoma is the most serious form of skin cancer, fatal in about 20 percent of the cases. Most forms of skin cancer are not fatal if treated but are often disfiguring.

POLITICAL RESPONSE

From the time of our initial discovery, Molina and I felt that this reduction in the ozone layer was too dangerous to continue and called for a ban on further emissions of CFCs to the atmosphere. The dollar value of chlorofluorocarbons that were going into the atmosphere in 1974 was $2 billion per year, and the value of the products using them were much larger. However, the chemical industry did not immediately leap at our suggestion that they should stop manufacturing and using chlorofluorocarbons.

The early days of our work and our early publications generated a great deal of political discussion. At that time, chlorofluorocarbons in the United States were primarily used as

FIGURE 7. Schematic diagram for effects resulting from loss of ozone in stratosphere


U.V.
OZONE LAYER
U.V.-B
1) LESS HEAT RELEASED IN UPPER ATMOSPHERE, LOWER TEMPERATURE GRADIENT ALTERED WINDS
2) MORE U.V.-B REACHES SURFACE
3) U.V.-B CAUSES BIOLOGICAL DAMAGE SKIN CANCER IMMUNE SUPPRESSION

propellant gases for aerosol sprays (which accounted for about two-thirds of the total use). As a result of the scientific work and the political concern, the United States announced in 1976 that it would ban the use of chlorofluorocarbons as propellants in aerosol sprays. Canada, Norway, and Sweden followed this lead, and many felt that the CFC-ozone problem had been solved.

But, in fact, there are many other uses of CFCs. The refrigerant in your home refrigerator and in automobile air conditioners is CFC-12. Polyurethane foam is made with chlorofluorocarbons. Nearly every piece of electronic apparatus in use has been cleaned with CFC-113 or with methyl chloroform, another chlorine-containing gas. As a result of growing use in products other than aerosols, the yearly release of CFCs has remained roughly constant for the last fifteen years. With a constant release rate and long atmospheric lifetimes, the total

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amount of chlorine in the atmosphere has steadily increased.

INTERNATIONAL ACTIVITY

The destruction of the ozone layer is an international problem, and the United States is not the only producer and user of CFCs. A United Nations Environment Programme to protect the ozone layer was signed in Vienna in 1985, and a protocol outlining proposed protective actions followed in Montreal in September 1987. The Montreal Protocol originally specified a 20 percent reduction in the release of fully halogenated chlorofluorocarbons by 1994 and a further 30 percent reduction in 1999. Even if the Montreal Protocol were fully implemented, the reductions would have only a minor effect on the amount of chlorine in the atmosphere before the end of the century. The provisions over the next ten years for production and use of CFCs by developing countries are part of the reason. The other element is the fact that CFCs are long-lived in the environment. However, with the observation of massive ozone loss over the Antarctic coupled with the knowledge that it was definitely caused by manmade chlorine, the Montreal Protocol was reevaluated in June 1990 and called for a complete phase out of CFC emissions.

The question of where we go in the next few decades depends on whether we follow the Montreal Protocol closely or whether we are negligent in its implementation and allow the levels of CFC emissions to continue to rise. There is no way that we are ever going to return, in our lifetime, to chlorine concentrations that were in the atmosphere as recently as the 1960s. We are going to live with ozone depletion. We do not know exactly what that is going to mean because there are time delays involved in reduced emissions and reduced atmospheric levels. At present there is a ten-year time delay while we are phasing out and then probably another ten-year delay for leakage from all of the refrigerators and air conditioners that we are using now. Then there are another few years until the CFCs work their way into the stratosphere. Following this pattern, the worst of the ozone reduction will occur about the year 2010 or 2015. We are twenty or twenty-five years away from that maximum.

POSSIBLE SUBSTITUTES

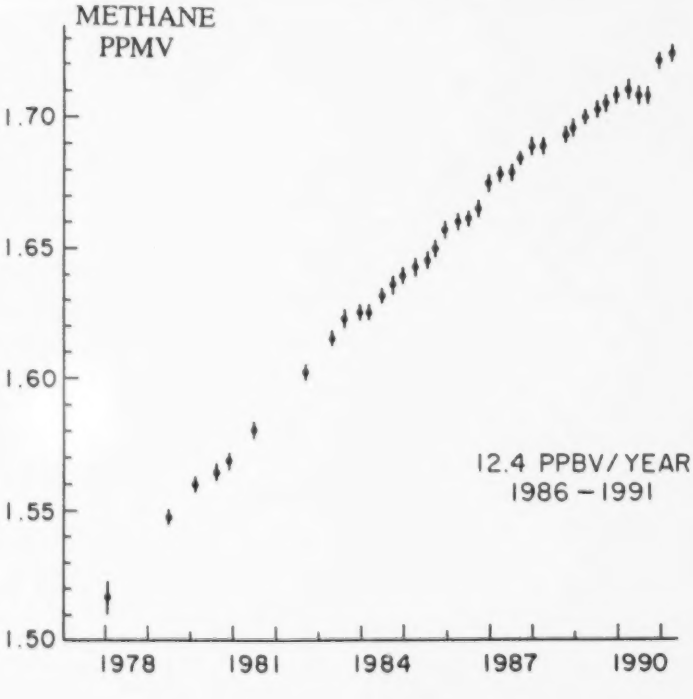
Much of our ability to reduce the use and manufacture of CFCs will depend greatly on developing reasonable substitutes. The apparent willingness and ability of industry to prepare substitutes and go along with an Environmental Protection Agency call for a total or nearly total phase-out of CFCs represents a tremendous policy shift in the United States over the past fifteen years.

I would like to make a note about possible substitutes. There is a sharp distinction in atmospheric behavior between chlorofluorocarbons that have no hydrogens (CFCs) and their hydrogen-containing analogs (HCFC). Those with hydrogen can be broken down in the troposphere and removed before they reach the stratosphere. The threat to stratospheric ozone then is greatly reduced. We need to keep in mind, though, that we live and breathe the troposphere and that the addition of any new breakdown products here should be looked at very carefully.

CLOSING COMMENTS

Dr. Keeling has recorded the increasing levels of carbon dioxide in the atmosphere; we and others have studied the increasing levels of methane in the atmosphere (Figure 8) and the increasing levels of chlorofluorocarbons in the atmosphere. All of those increasing levels of chemicals in the atmosphere are the result of activities of mankind. The driving force for the activities of mankind that result in increased emissions of CO_2, CH_4, or CFCs, over the last

FIGURE 8. Global average atmosphere methane concentrations since 1978 (D. Blake and F.S. Rowland).



couple of centuries, has been the improvement of our standard of living. Traditionally, the way we have improved our standard of living has been to use more energy and more materials and to release the waste products into the atmosphere, land, or oceans. Rapidly increasing population growth coupled with the demand for a higher standard of living is the underlying problem. If we continue to act as we have, we will continue to see a rapid change in the atmosphere. The question presumably requires consideration of population control, conservation and better use of our limited resources, and inclusion of the real costs of emission of our waste products as we increase our standard of living. It is not too soon to consider these very serious issues. While we are beginning to understand the science, we must also begin to understand and change human behavior.

ADDITIONAL READING

Blake, D.R. and Rowland, F.S. 1988. Continuing worldwide increase in tropospheric methane, 1978 to 1987. *Science* 239:1129–31.

Harris, N., Rowland, F.S., Bojkov, R. and Bloomfield, P. 1988. Wintertime losses of ozone in high northern latitudes. NASA Polar Ozone Workshop. Aspen, Colorado.

Molina, L.T. and Molina, M.J. 1987. Production of Cl_2O_2 from the self-reaction of the ClO radical. *J. Phys. Chem.* 91:433–36.

Rowland, F.S. 1974. Aerosol sprays and the ozone shield. *New Scientist* 64:717–20.

Rowland, F.S. and Molina, M.J. 1975. Chlorofluoromethanes in the environment. *Rev. Geophys. Space Phys.* 13:1–35.

WMO-NASA. 1986. *Atmospheric Ozone 1985*. 3 vols. WMO Global Ozone Research and Monitoring Project, rep. no. 16.

Monitoring Ozone from Your Classroom

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The machine does not isolate man from the great problems of nature but plunges him more deeply into them.
*—Antoine de Saint Exupery**

Section I
When Does the Ozone Hole Appear?

Goal
To determine the time of year that the ozone hole is most apparent, by using actual data.

Key Concepts
- The ozone hole is only apparent during certain months.
- Although the term ozone "hole" is widely used in popular and scientific literature, the phenomenon is more correctly described as a low concentration of ozone.

Overview
Students construct a graph using raw data obtained from orbiting satellites to determine the time of year that the ozone hole is most apparent. Students also gain experience with managing a large amount of data.

Materials
- Data table: Ozone Concentration For Latitudes 90°S to 30°S, 1987 (pages 61-62)
- Graph paper

Procedure
Referring to the data in the Ozone Concentration data table:

a. Determine scale for each axis; plot OZONE CONCENTRATION (Dobson Units/DU) on the vertical axis and TIME (days) along the horizontal axis.
b. Using these data and the graph paper, construct a graph showing the relationship between ozone concentration and day of the year.
c. Label the months on your graph, correlating numbers with dates.
NOTE: There are a lot of data here. You may want to treat them in one of the following ways: (1) plot only every tenth day, (2) average

* *Wind, Sand And Stars*

every 10 days' worth of data and plot this average value, (3) plot a small portion of data, then combine your efforts with classmates' work to produce one large graph. Be sure to use a constant scale.

TO THE STUDENT

Observe

1. When is the ozone concentration lowest? Give month and season.
2. When is the ozone concentration highest? Give month and season.

Interpret

3. Do you need to plot each day's Dobson Units? Explain.
4. How is the ozone level related to the time of year?
5. Which is the best description of a low number of Dobson Units?
   a. An area of no ozone
   b. An area of low concentration of ozone molecules
   c. An area of high concentration of ozone molecules
6. Would you describe this phenomenon as a "hole"? Why or why not?

Apply

7. Why do you think the ozone level begins to decrease when it does?
8. What is the value of using an entire class to analyze these data?

Section II

Have Antarctic Ozone Levels Changed In Ten Years?

Goal

Students will generate and interpret false color plots of ozone depletion in Antarctica over a ten year-period.

Key Concepts

- Ozone concentrations over Antarctica have changed in the last ten years.
- Using color to represent data simplifies data interpretation.

Overview

Ozone plots published in newspapers and magazines may be familiar to you, but do you understand them? In this activity students generate and interpret such plots to gain a better understanding of ozone depletion in Antarctica. This exercise models current science by using color codes to facilitate data interpretation.

Materials

- Ozone plots: Total Ozone Monthly Mean, October 1980-1989 (pages 65-69)
- Ozone plot: Antarctica: South Polar Plot (page 63)
- Colored pencils - 16 different colors

Preparation

Line drawings may be enlarged on a copying machine—enlarging 150 percent will put one plot horizontally on a standard page. The line drawing, Antarctica: South Polar Plot, can be made into a transparency and superimposed over plots to provide geographical information. Divide your class and generate a few series of plots to save time.

Note: *Each series may have a different color key but the color key must be the same within a series.*

Procedure

Working in student groups:

a. Determine color values for the Dobson Unit ranges. (Technicians utilize computers to assign specific colors to specific ranges of Dobson Units. For example, values 100-124 may be yellow; 125-149 may be orange, and so on.)
b. Color the key on each of the ten plots, using your chosen colors.
c. Color each plot, using your color key to guide you.
   Note: *Some plots may show only a few of the colors from their keys.*

TO THE STUDENT

Observe

1. List the value and year for the lowest ozone concentration in these data.
2. Describe the geographic location of the ozone hole.

Interpret

3. Describe the general trend of ozone values from 1980 to 1989.
4. Does the ozone always drop from year to year?
5. Why are ten years of data better than two?

Apply

6. Should we make hundred-year predictions using ten years of data? Discuss.
7. How would a plot for a specific day differ from a monthly mean plot? Why interpret monthly mean plots versus daily plots?
8. Collect pictures of ozone plots from magazines and newspapers. Compare these plots with ones you generated in this experiment.
9. If your class produced more than one series of plots with different color keys, compare these keys. Which are the easiest to understand? Which do the best job of depicting the data?

Glossary

Austral—Southern, or having to do with the southern hemisphere.

Chlorofluorocarbon (CFC)—A compound containing carbon, chlorine and fluorine atoms; an example is Freon™, used in air conditioners and refrigerators.

Dobson Unit—A measurement of the thickness of the ozone layer, by an equivalent layer of pure ozone gas at normal temperature and pressure at sea level. In other words, 100 DU = 1 mm of pure ozone gas at normal temperature and pressure at sea level.

Ozone—A form of oxygen produced by energy from ultraviolet radiation or electricity such as lightning. When present in the air in higher concentrations than normal, it can be detected by its sharp pungent odor, which resembles weak chlorine.

Polar Night—The period of total darkness during the winter months that occurs at both of Earth's polar regions.

Ultraviolet Rays—The invisible rays in the part of the spectrum beyond violet. The wavelength of ultraviolet rays is shorter than those of visible violet and longer than those of x-rays.

Topics for Further Research

- *Nimbus-7* satellite
- SSBUV (Shuttle Solar Backscatter Ultraviolet) instrument
- Chlorofluorocarbon

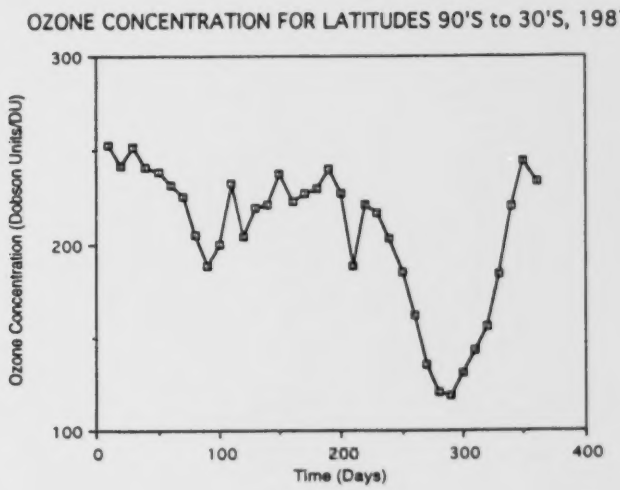
More Ideas:

- Color code and interpret the seasonal plots provided (January, April, July, October 1987).
- Research ozone changes according to latitude.
- Research ozone measuring techniques prior to 1980.
- Compare Arctic and Antarctic ozone levels.
- Update these experiments by researching current ozone values.

TO THE TEACHER

Section I: According to these data, the ozone reaches its lowest values in October, which is spring in the Southern Hemisphere. The highest concentrations of ozone occur over Antarctica in January, mid-austral summer.

Student graphs should look something like the one below.



Sometimes too much data confuse rather than clarify an issue. This activity focuses on trends, thus it is not necessary to plot each day's Dobson Units. The ozone levels are fairly consistent throughout the year, with a noticeable drop in September and October. Low

readings of ozone mean there are fewer ozone molecules in that particular area. The ozone hole is more aptly described as a low concentration, since to date there have been no recorded readings of zero for ozone.

Ozone concentration is lowest in the spring, following the cold winter. Scientific studies link ozone level to atmospheric temperature. Students can benefit from each others' work, accomplishing more as a class than they could individually. Before scientists had wide access to super-computers, they often employed rooms full of people using calculators to manage large amounts of data.

Section II: The measurements for 1987 and 1989 are equally low at 125 DU. The greatest ozone depression is primarily over the Antarctic continent. Using ten years of data, the general downward trend of ozone levels is quite obvious, but would not be clear with only two years of data (note: 1987 and 1988).

We have not been collecting satellite data long enough to yield statistically accurate, long-term predictions, and must, therefore, incorporate data from ground-based ozone-monitoring equipment as well. More data are usually preferred and generally yield better (more reliable) results than less data. Data sets, both small and large, must be subjected to sophisticated statistical analysis to test their reliability. Daily plots are more complex and show far more detail. Monthly average plots are easier to interpret because the plots are simpler, without the extremes. Collected ozone plots should look similar to the ones your class generates. The color keys will differ since these are nonstandard and dependent upon individual scientists. Color keys are often based on the visible spectrum, or rainbow, and range from light to dark for high to low values. You will note larger differences if you collect a daily plot, which will look far more complex for reasons described previously. (Color keys are a matter of personal preference, though some communicate better than others.) Students should be able to support their conclusions.

What's the Science? The large, rapid, and unexpected decrease in the amount of springtime Antarctic ozone over the last decade cannot be attributed to known natural processes. Although there is increasing evidence that present-day pollution plays a major role in this, scientists do not, at this time, have a model that adequately simulates the chemistry or weather conditions that accompany ozone depletion. The following paragraphs outline our current understanding of ozone chemistry.

As sunlight strikes the upper atmosphere, oxygen molecules react to form ozone.* The resulting ozone concentration is rather small but it has a very important effect. The ozone gas absorbs much of the Sun's ultraviolet radiation,** which would harm life on Earth in excessive amounts. As ozone absorbs ultraviolet light energy, the

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* A molecule of ozone consists of three atoms of oxygen bonded together.

** A component of sunlight

temperature of the surrounding air increases. This warmer air does not mix with the cooler air beneath it, confining the majority of the ozone gas to the stratosphere (approximate altitude 25 km or 15 mi).

Ozone may remain in the atmosphere or decompose back to oxygen. Two things seem to speed up the natural process of ozone destruction: (1) the presence of pollutants such as oxides of nitrogen and chlorofluorocarbons (CFCs) which catalyze* the reaction, and (2) the presence of polar stratospheric clouds, which provide aerosol surfaces needed for the catalyzed reaction. Also, certain weather conditions, such as sunlight and extremely cold temperatures, are necessary for the accelerated ozone loss. Winds, high in the atmosphere above the South Pole, create a stable vortex** that concentrates the cold, and thus the ozone destruction. The resulting severe depletion of ozone is localized above Antarctica and is generally referred to as the ozone hole.

The ozone hole appears in the austral spring, following the continent's coldest season and polar night. Ozone depletion over the Arctic is not as well defined as in Antarctica. The relatively warmer northern climate, different distribution of landmasses, and lack of a stable windy vortex are thought to be reasons for this.

The ozone hole cannot be seen by the human eye, but must be measured by special instruments. Since 1978, the Total Ozone Mapping Spectrometer (TOMS), an instrument aboard the *Nimbus-7* satellite, has been observing ozone levels by measuring ultraviolet radiation that is backscattered by the atmosphere or reflected from Earth's surface.

TOMS measures the total ozone from the ground to an altitude of 50 km. Each section of the flat ozone plots, generated in this activity, represents a column of atmosphere thousands of meters thick. TOMS meas- ures ozone values from above for the entire depth of the atmosphere. Since this type of ozone mapping requires sunlight, measurements cannot be made at night or in polar areas during their season of 24-hour darkness (polar night). Although TOMS collects ozone data for the entire planet, the data in these lab exercises are only from the Southern Hemisphere. The Shuttle Solar Backscatter Ultraviolet instrument, flown on various Shuttle missions, including STS-34, assists scientists in calibrating TOMS. Ozone levels are recorded in Dobson Units, a measurement of the thickness of ozone layer, by an equivalent layer of pure ozone gas at normal temperature and pressure at sea level. In other words, 100 DU = 1 mm of pure ozone gas at normal temperature and pressure at sea level. The average amount of ozone at mid latitude is 3 mm or 300 DU.

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* In this instance, the reaction is speeded up.

** A whirlpool of wind.

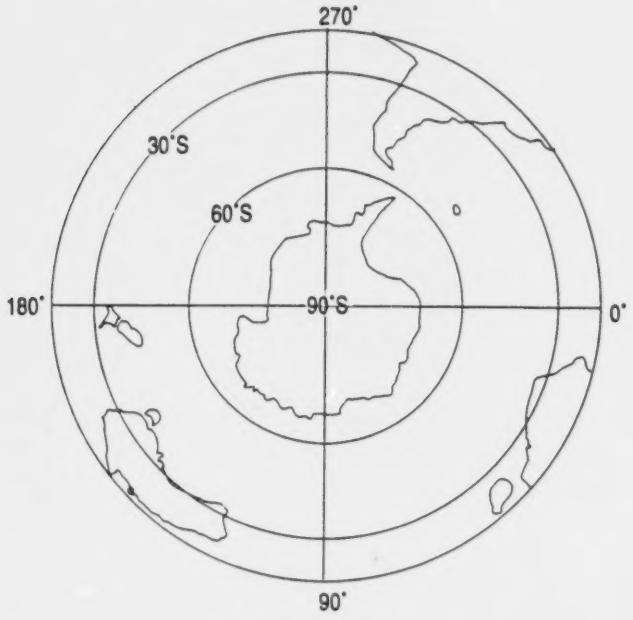
Ozone Concentration for Latitudes 90°S to 30°S, 1987

DAY	DU	DAY	DU	DAY	DU	DAY	DU
1	255	47	242	93	200	139	219
2	254	48	238	94	201	140	221
3	254	49	238	95	197	141	227
4	248	50	238	96	199	142	218
5	251	51	226	97	205	143	217
6	253	52	228	98	201	144	225
7	254	53	234	99	206	145	217
8	251	54	240	100	200	146	216
9	251	55	242	101	205	147	218
10	253	56	239	102	208	148	228
11	257	57	239	103	210	149	227
12	255	58	240	104	222	150	237
13	255	59	236	105	227	151	226
14	253	60	231	106	224	152	223
15	254	61	237	107	218	153	203
16	253	62	238	108	222	154	222
17	252	63	244	109	225	155	207
18	251	64	236	110	232	156	206
19	245	65	222	111	235	157	212
20	242	66	224	112	231	158	229
21	251	67	227	113	229	159	234
22	246	68	220	114	232	160	223
23	251	69	219	115	216	161	233
24	251	70	225	116	213	162	219
25	249	71	219	117	208	163	215
26	246	72	208	118	219	164	231
27	250	73	213	119	227	165	235
28	249	74	210	120	204	166	233
29	247	75	217	121	215	167	222
30	252	76	217	122	210	168	228
31	246	77	217	123	212	169	216
32	250	78	210	124	213	170	227
33	250	79	203	125	213	171	229
34	249	80	205	126	216	172	209
35	249	81	206	127	233	173	203
36	248	82	208	128	235	174	220
37	246	83	201	129	229	175	220
38	243	84	198	130	219	176	229
39	243	85	203	131	226	177	233
40	241	86	207	132	228	178	231
41	244	87	204	133	220	179	237
42	244	88	203	134	213	180	230
43	240	89	188	135	211	181	235
44	243	90	188	136	228	182	230
45	244	91	195	137	227	183	221
46	233	92	193	138	230	184	217

Ozone Concentration for Latitudes 90 °S to 30°S, 1987 *(cont.)*

DAY	DU	DAY	DU	DAY	DU	DAY	DU
185	225	231	201	277	112	323	167
186	232	232	217	278	106	324	165
187	228	233	210	279	112	325	160
188	227	234	219	280	121	326	157
189	228	235	218	281	119	327	164
190	240	236	212	282	117	328	170
191	234	237	203	283	127	329	174
192	238	238	207	284	132	330	184
193	233	239	193	285	127	331	181
194	233	240	203	286	125	332	184
195	209	241	206	287	125	333	191
196	207	242	210	288	122	334	197
197	223	243	209	289	121	335	200
198	215	244	194	290	119	336	209
199	229	245	202	291	124	337	202
200	227	246	189	292	122	338	210
201	235	247	204	293	125	339	219
202	230	248	173	294	125	340	220
203	205	249	173	295	120	341	215
204	204	250	185	296	124	342	227
205	234	251	173	297	129	343	228
206	229	252	175	298	128	344	231
207	244	253	178	299	133	345	246
208	225	254	171	300	131	346	249
209	208	255	161	301	135	347	248
210	188	256	158	302	133	348	252
211	172	257	166	303	133	349	247
212	214	258	160	304	135	350	244
213	201	259	161	305	141	351	245
214	208	260	162	306	143	352	242
215	208	261	164	307	142	353	242
216	215	262	164	308	141	354	250
217	207	263	151	309	141	355	249
218	190	264	147	310	143	356	249
219	204	265	144	311	142	357	247
220	221	266	149	312	143	358	240
221	220	267	151	313	143	359	231
222	228	268	146	314	147	360	233
223	224	269	144	315	141	361	236
224	220	270	135	316	146	362	244
225	200	271	131	317	146	363	242
226	230	272	122	318	153	364	242
227	199	273	112	319	154	365	243
228	183	274	111	320	156		
229	172	275	119	321	155		
230	217	276	124	322	163		

ANTARCTICA



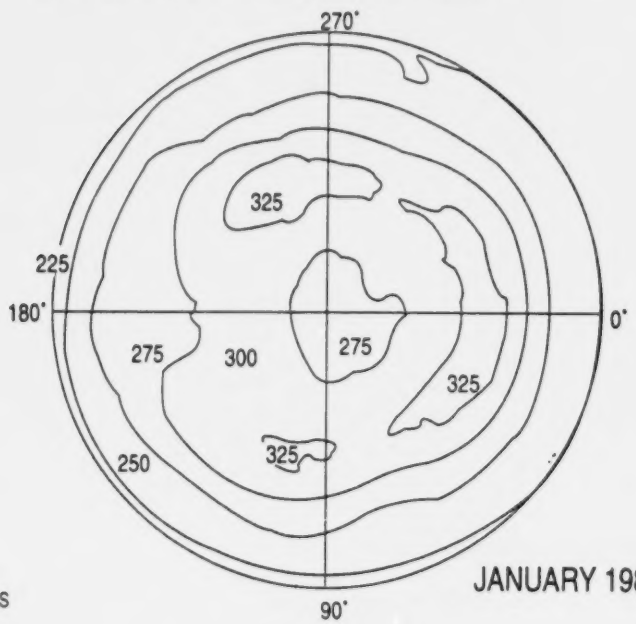
Lines of longitude

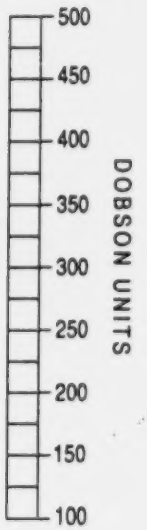
Lines of latitude

NOTE: latitude of outer circle is approximately 10°S.

South Polar Plot

TOTAL OZONE MONTHLY MEAN



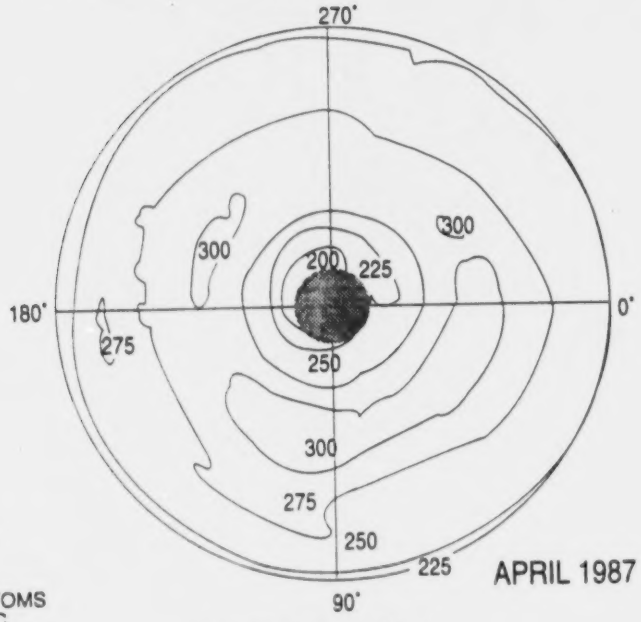


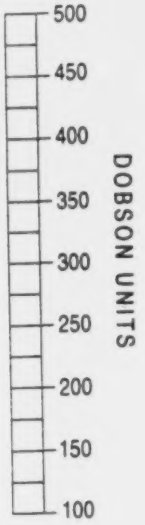
JANUARY 1987

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN





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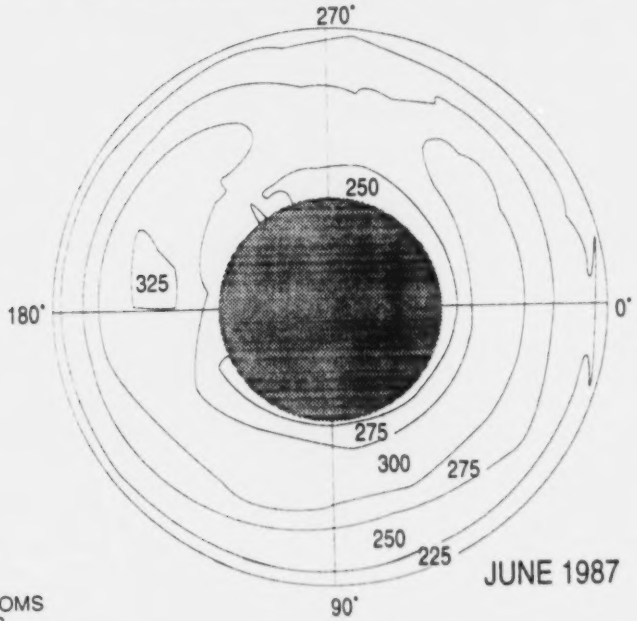
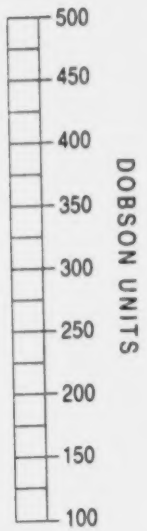
APRIL 1987

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN





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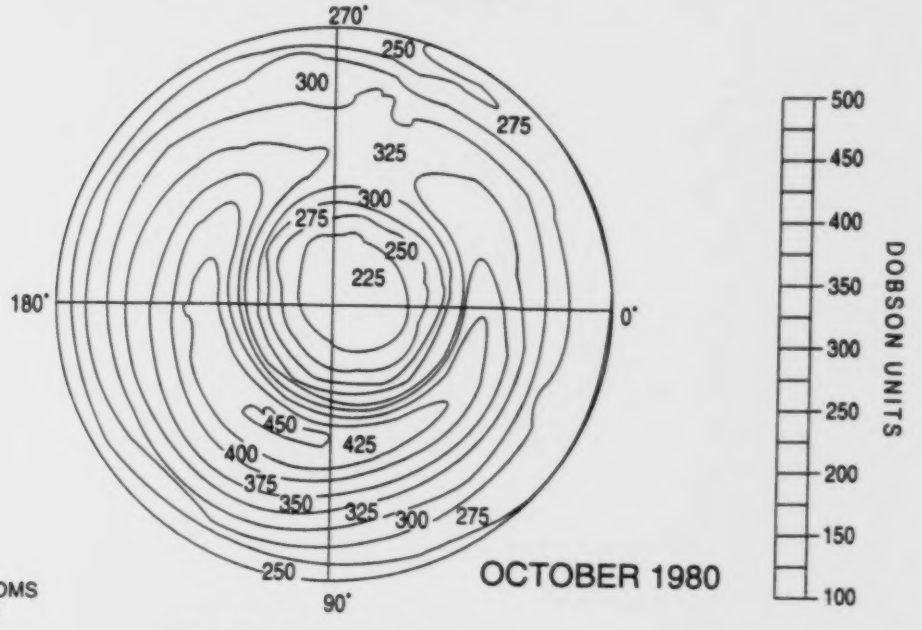
JUNE 1987

Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN

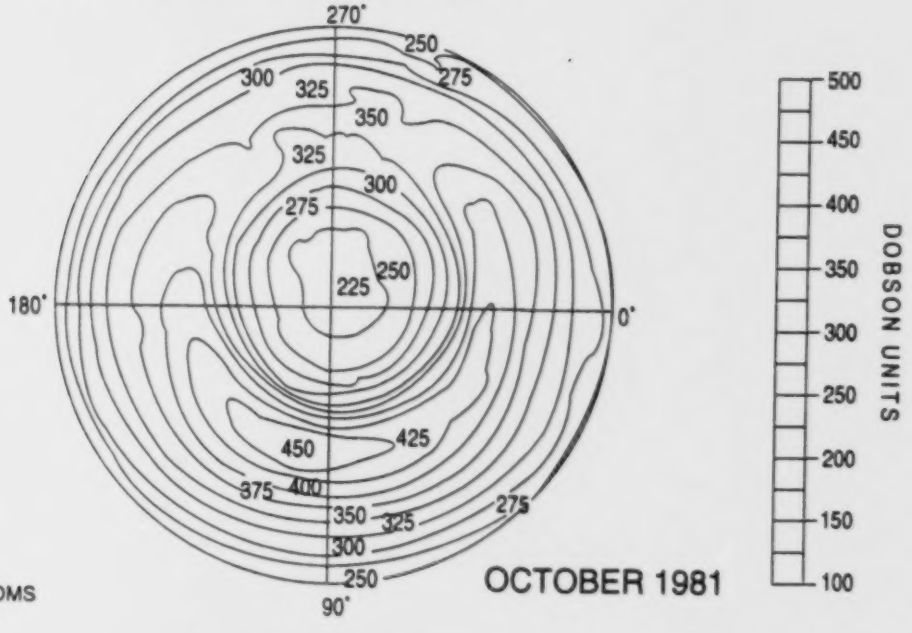


Nimbus-7: TOMS
NASA/GSFC

OCTOBER 1980

South Polar Plot

TOTAL OZONE MONTHLY MEAN



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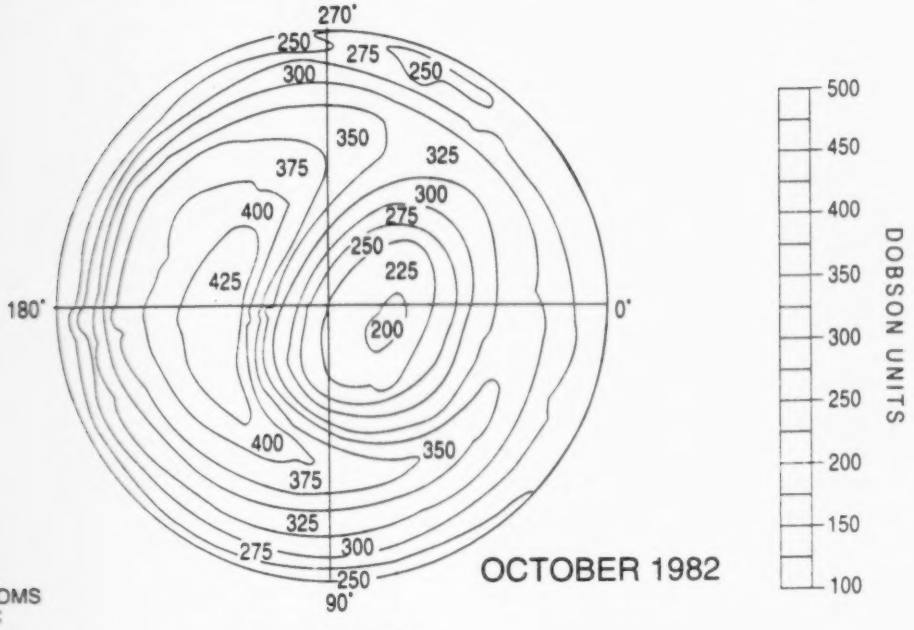
OCTOBER 1981

South Polar Plot

TOTAL OZONE MONTHLY MEAN



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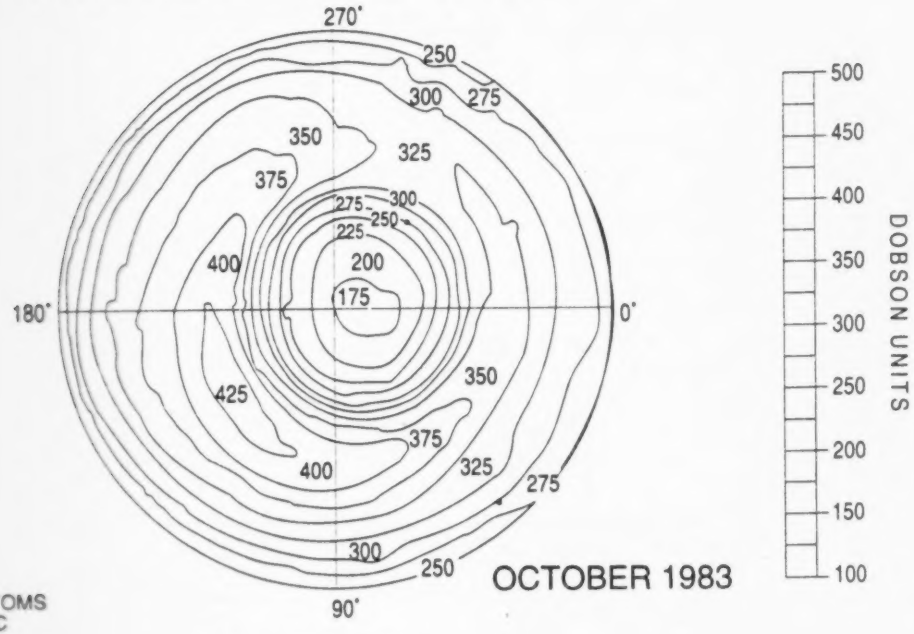
NASA/GSFC

South Polar Plot

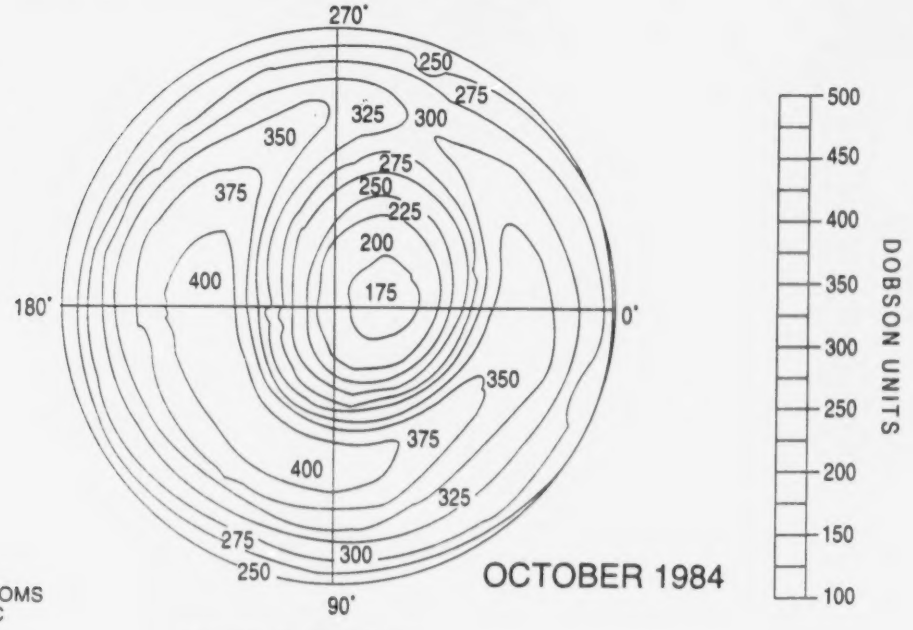
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

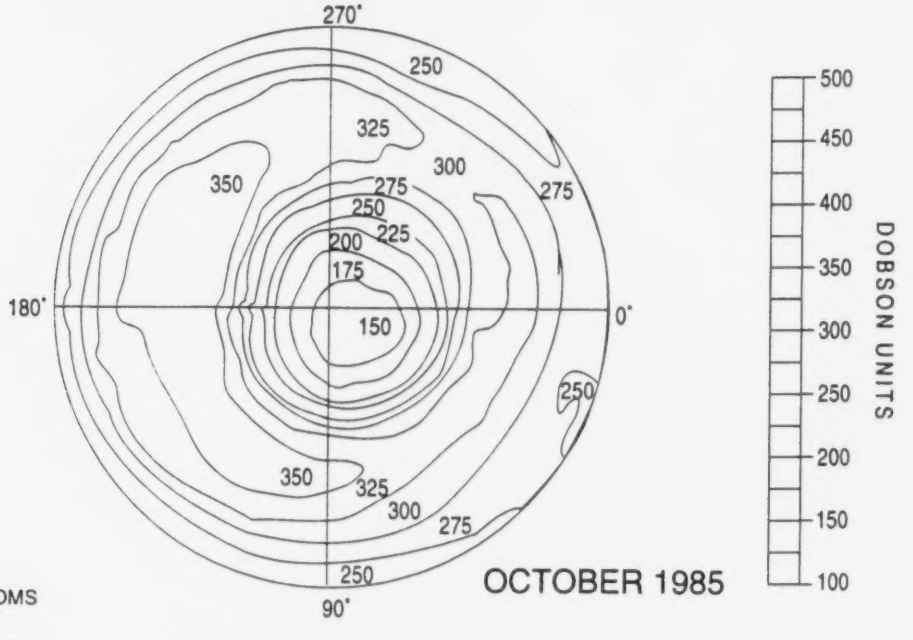
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

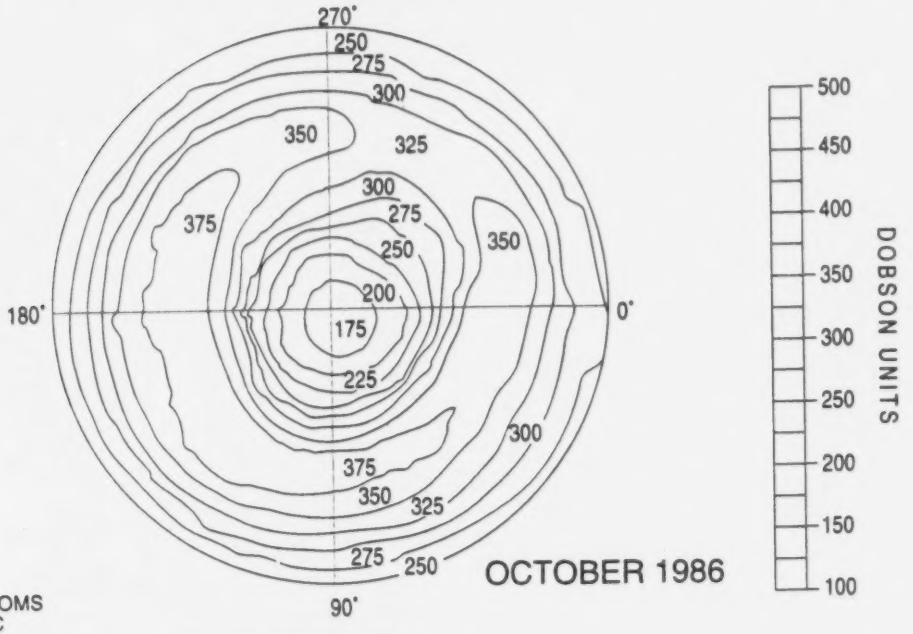
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

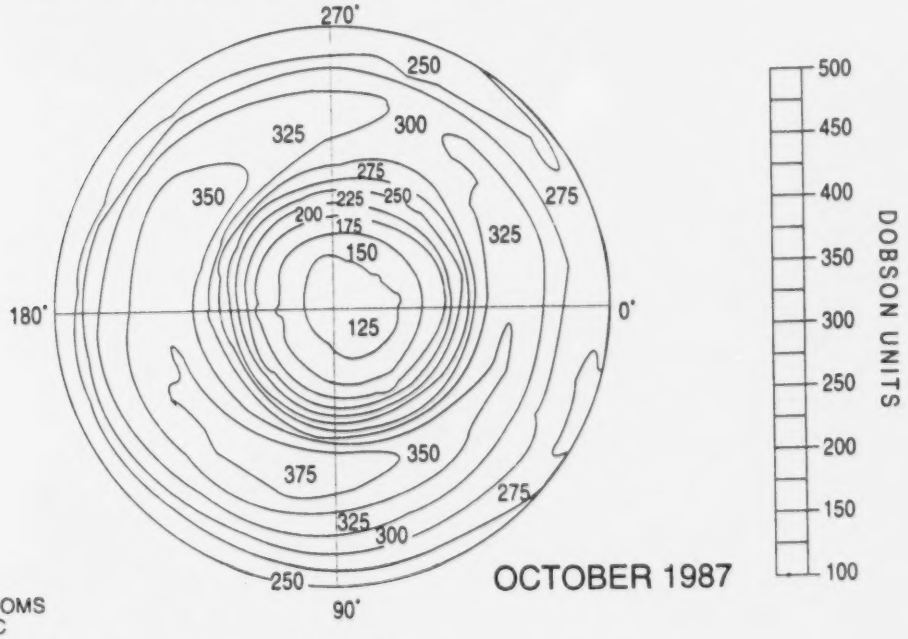
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

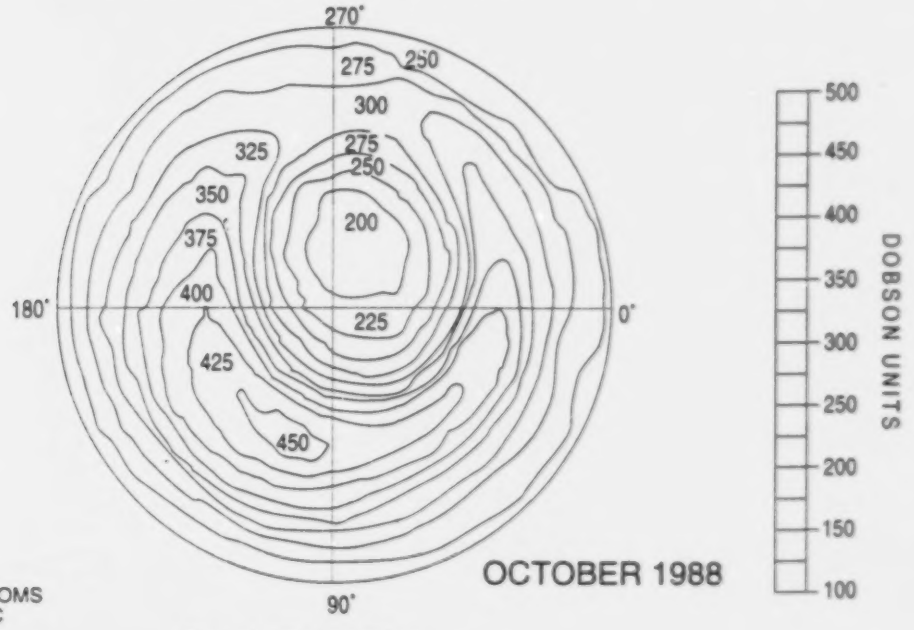
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

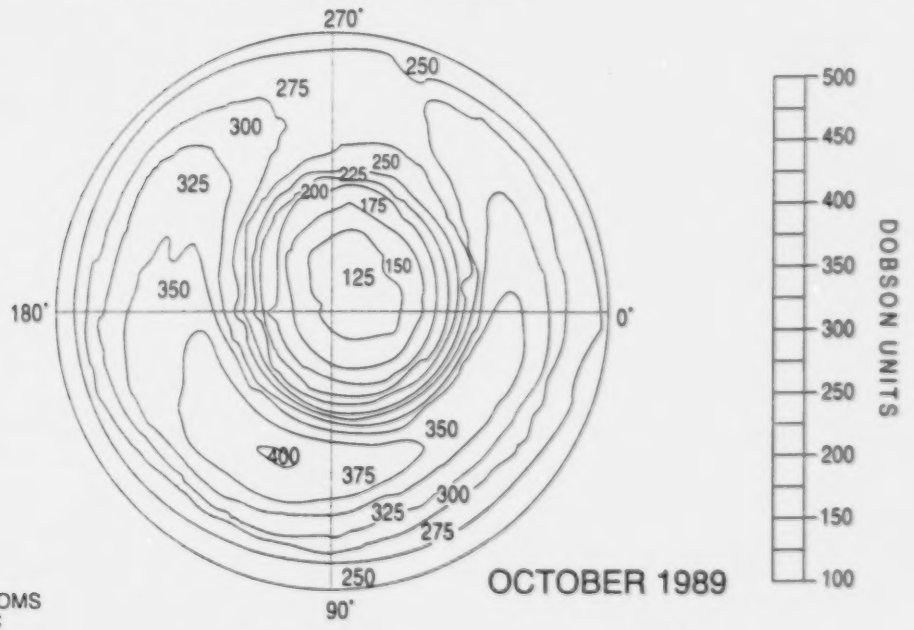
TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

TOTAL OZONE MONTHLY MEAN



Nimbus-7: TOMS
NASA/GSFC

South Polar Plot

OZONE TAG

NAME: Jan Weathers Dykes

SCHOOL: Rosenwald Middle School

SCHOOL DISTRICT: Bay County

GRADE/SUBJECT: 6th Grade/General Science

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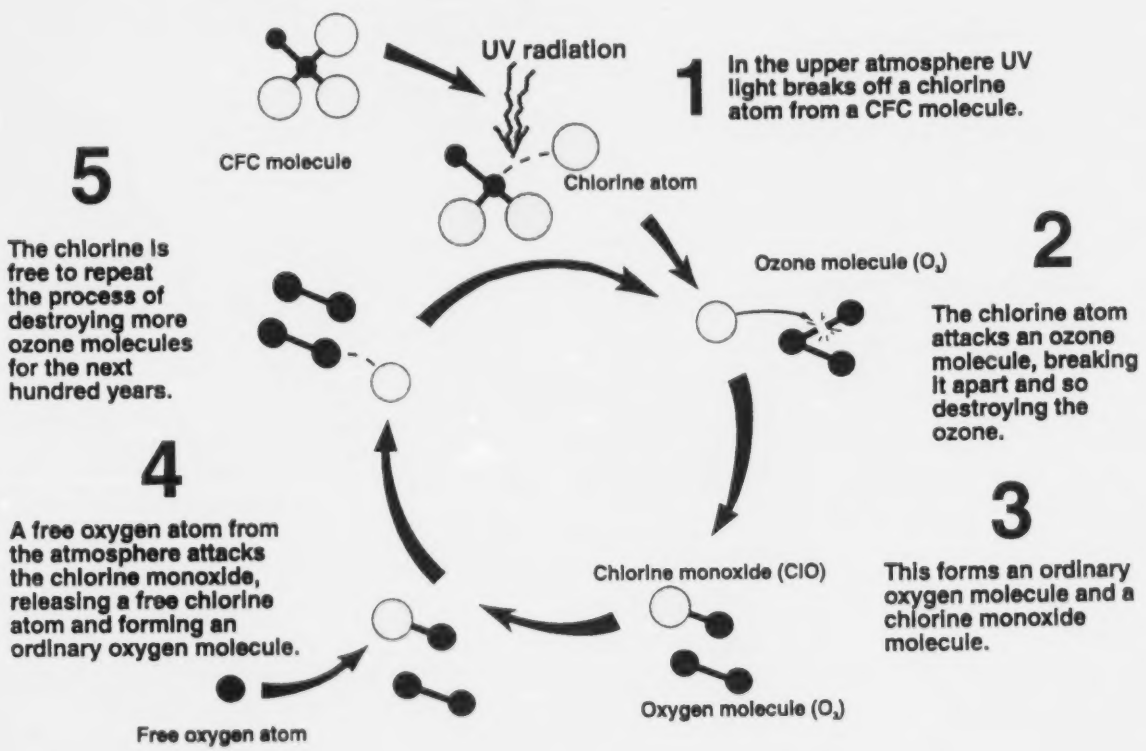
TOPIC AND ISSUE STATEMENT: Ozone is a form of oxygen. The ozone found in the stratosphere screens ultraviolet radiation from the sun. Currently, man-made chemical compounds containing chlorine and bromine are attacking our stratospheric ozone. Chlorofluorocarbons and bromofluorocarbons are the most common. If this trend continues, more ultraviolet radiation will penetrate the stratosphere and reach the earth's surface. Increased ultraviolet radiation can cause skin cancer.

An understanding of the chemical reactions involved in ozone depletion can increase an individual's understanding of the entire phenomenon. This lesson is designed to teach the chemistry of ozone depletion in a simplified manner. The basic reaction chain which will be symbolized is pictured below.


UV radiation
1
In the upper atmosphere UV light breaks off a chlorine atom from a CFC molecule.
CFC molecule
Chlorine atom
5
The chlorine is free to repeat the process of destroying more ozone molecules for the next hundred years.
Ozone molecule (O_3)
2
The chlorine atom attacks an ozone molecule, breaking it apart and so destroying the ozone.
4
A free oxygen atom from the atmosphere attacks the chlorine monoxide, releasing a free chlorine atom and forming an ordinary oxygen molecule.
3
This forms an ordinary oxygen molecule and a chlorine monoxide molecule.
Chlorine monoxide (ClO)
Oxygen molecule (O_2)
Free oxygen atom

OBJECTIVES:

1. The student will be able to explain the role of stratospheric ozone.
2. The student will be able to predict at least three ways in which depleted ozone would change her/his lifestyle.
3. The student will be able to describe the process by which chlorine or bromine compounds can break down ozone molecules.
4. The student will be able to relate the amount of chlorine or bromine in the atmosphere to the rate of ozone depletion.

MATERIALS: Colored ribbon, chart paper, markers, paper, pencil, and stopwatch.

REFERENCES: What Would It Be Like To Live In A World Where The Sun Was Dangerous? pamphlet.

STRATEGY: This lesson will be taught after a general introduction of ozone depletion. It allows students to enhance their understanding before they do further exploration activities and begin to propose solutions. A basic understanding of atoms and molecules is a prerequisite.

ACTIVITY: The teacher will review the concept of ozone depletion, discussing major causes and resulting problems. The teacher will guide the students through the reactions associated with this process. (See Topic and Issue Statement.) Students will then go outside to play Ozone Tag.

For this game, one student will be designated as a chlorine atom which UV energy has released from a chemical compound. This student should use a piece of colored ribbon as an armband or headband. Other students should be oxygen atoms and should "number-off" from one to four. The ones, twos, and threes will link in groups of three by holding hands ( ). They represent ozone molecules. Fours represent free oxygen atoms.

At a signal, the teacher will begin timing, and the chlorine atom will begin to pursue ozone molecules. The ozone molecules may try to avoid being captured but must stay linked. When the chlorine atom catches a member of the ozone molecule, that member must bond with the chlorine atom, leaving a diatomic oxygen molecule. ($Cl + O_3 \rightarrow ClO + O_2$) All diatomic oxygen molecules should join both hands to represent double bonds ( ). The chlorine atom and oxygen atom remain linked until the chlorine atom catches a free oxygen atom. Then the two oxygen atoms join in a double bond and the chlorine atom is free to attack another ozone molecule. This process should be followed until all ozone molecules have been broken down to diatomic oxygen molecules or diatomic oxygen molecules and one chlorine monoxide molecule (depending on the number of participants). The teacher, or a designated timekeeper, should record the amount of time required for one chlorine atom to break down all of the ozone. The game should then be repeated twice: with two chlorine atom pursuers and with three. The time needed to break down the ozone should be recorded each time.

After three games, the teacher and students will return to the classroom. The students will work cooperatively to graph the results of each game round on chart paper. This graph should illustrate that increased chlorine levels increases the rate of ozone destruction. Remind students that the atom could also be a bromine atom. The teacher can then review major ideas, linking them with the game.

EXTENSIONS:

1. Have students design a beach clothing line for the post-ozone era. How would styles change? Why?

2. Have students use colored marshmallows and pretzel sticks to construct molecules that show the reaction they acted out in the game.

3. Students can research products and companies to generate their own list of ozone-safe products in different categories (hairspray, deodorant, or other products).

EVALUATION: Students will answer the following questions:

1. Describe the importance of ozone within the stratosphere.

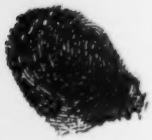
2. If ozone depletion continues, what are three lifestyle changes you will have to make? Why?

3. Explain the process by which bromine or chlorine atoms break down ozone. You can use pictures or examples from the game to help you explain.

4. What effect would increased chlorine levels have on ozone depletion?

☛ Case No. 2 What is causing thinning of the ozone layer?

CLUES:



Amounts of ozone in the stratosphere are changing all the time. The seasons of the year, changing winds in the middle atmosphere, and even **sunspots** affect ozone levels. At the same time that sunspots appear, UV radiation from the Sun seems to increase. The amount of UV radiation can increase or decrease the number of ozone molecules. All of these are natural changes.

Anthropogenic changes, those caused by humans, are occurring as well. In the lower atmosphere, **chlorofluorocarbons** (CFCs) released by industry act as greenhouse gases, overheating Earth. When they rise to the stratosphere, they break down into other chemicals, eventually producing **chlorine**, the same chemical that purifies drinking water and swimming pools. In the stratosphere, chlorine destroys ozone, allowing more dangerous UV radiation to reach our planet. The two CFCs used to blow plastic foam and to cool refrigerators and air conditioners are the most widely used. Scientists have found that these chemicals are increasing in the atmosphere at an annual rate of about 5 percent. Other CFCs and gases that destroy ozone are also increasing.

In some locations, scientists have detected thin spots in Earth's protective ozone layer. In 1985, British researchers discovered that the amount of ozone expected to be over the Antarctic during the spring had decreased by almost half since the 1960s. Why over the Antarctic? Chemicals like CFCs that destroy ozone exist everywhere over Earth. Above the Antarctic, high, icy-cold clouds of water and other chemicals combine to make chlorine into a form that is more active. Combined with sunlight, this chlorine destroys the protective ozone layer. Some smaller losses of ozone have occurred above the Arctic also.

Temperatures over lower latitudes are too warm for these ice clouds to form, but other reactions can have the effect of reducing ozone. Clouds are made up of water vapor, and water vapor in the atmosphere may be increasing because of human activities. As more high clouds form, more reactions can take place. In fact, ozone over the Northern Hemisphere has decreased slightly in the last 20 years.

Investigation A: Recycled Greenhouses

If you would like to make your own greenhouse and recycle at the same time, here is an activity for you. (This makes one greenhouse.)

Materials Needed

- ✓ **one empty 2-ℓ soft drink jug with removable plastic base**
- ✓ **about 450 g of potting soil**
- ✓ **one package of seeds (tomato, green bean, pumpkin, or watermelon work well)**
- ✓ **water to moisten soil**
- ✓ **scissors**

Procedure

Carefully remove the plastic base from the jug. With the scissors, cut off the top of the jug, beginning just at the point where the jug curves upward toward the spout. Fill the base with potting soil to within about 1 cm of the top. Plant seeds according to instructions on the package. Water to moisten soil. Turn the larger piece of the jug upside down and insert into the base. Carefully move the soil toward the center if the top will not fit. Place this "greenhouse" in the sunlight. Keep the soil moist. Once the seedling has appeared, watch closely to be sure that heat in the greenhouse does not become too intense.

Questions

❶ When the greenhouse is heated in the sunlight, where does moisture collect?

❷ Why does this happen?

❸ If this greenhouse overheats, what can happen to the seedling?

❹ How does this relate to Earth's enhanced greenhouse effect?

Investigation B: Welcome to the "O"-Zone.

There typically are only one to ten units of ozone in every million units of gas or particles in the stratosphere, but they protect Earth by absorbing most of the UV rays from the Sun. ATLAS 1 instruments measure ozone in parts per million (ppm). It may be difficult to imagine such small amounts, so try this activity

Materials Needed

- ✓ **measuring tape about 3-m long**
- ✓ **large, good quality cardboard box, about 61 x 61 x 61 cm**
- ✓ **paring knife or scissors**
- ✓ **glue**

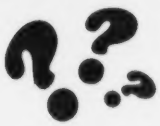
Procedure

Cut the box into flat sheets. Divide the sheets into 1-cm squares, marking the squares with a pencil. Cut out the cardboard squares. Stack the flat squares on top of each other to form blocks about 1 cm high, and glue. These cubes will represent units of ozone.

Measure the length, width, and height of your classroom in centimeters. Multiply the three numbers together to find the room's volume in cubic units. To make a model of 1 ppm, divide by one million (move the decimal point six places to the left) to find out how many of these cubes you will need for the volume of your classroom. To make 10 ppm, multiply your answer by 10.

Suspend the cubes around your classroom on pieces of string. This gives you some idea of the amount of ozone in the stratosphere. Remember that the rest of the space is not empty; it is filled with units of other gases, particles, and water vapor.

Questions



From what this investigation shows you, do you think a great deal of ozone is required to absorb UV radiation?

Investigator's Notebook: Hole-y Moly!

The ozone hole over the Antarctic is most noticeable in the Antarctic or austral spring, which occurs in October. During this season, increasing sunlight and frigid temperatures combine to convert chlorine into active forms that break down ozone. Later in the spring, the area of low ozone, sometimes called a hole, begins to break up. Higher ozone air from the mid latitudes moves toward the poles and "fills in" the hole. The low-ozone air moves into lower latitudes, and the atmosphere over the Antarctic becomes more normal. However, the hole has reappeared every year since it was first detected in the mid 1980s.

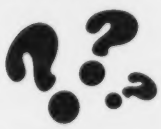
From space, ATLAS 1 scientists measure concentrations of ozone and other gases in the atmosphere. With surveys made over a long period of time, they assess changes in Earth's essential atmosphere.

To visualize decreases in the amount of ozone over the Antarctic, try this activity.

Procedure

Following the numbers, color the numbered areas within the heavy black lines. The yellow indicates areas of heaviest ozone concentration, and purple indicates areas where the ozone is thinnest. Carefully cut out the printed squares. Place the blocks in order, stacking with the earliest year at the bottom. Staple the block at the top left and right. Use your thumb to fan the papers, creating the illusion of a moving picture.

Questions



❶ What has happened to the areas rich in ozone?

❷ What advantages are there to viewing the atmosphere from space?

Relating Science to . . .

Creative Thinking: List 10 ideas for packaging that use only natural, recyclable materials.

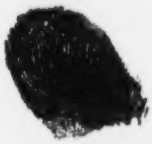
Helping Mother Earth

Plastic can be recycled, too. Recycling saves energy and preserves natural resources, so make sure that the plastic jugs used in any experiments are taken to a recycling area.

OCTOBER 1979
OCTOBER 1980
OCTOBER 1981
OCTOBER 1982
OCTOBER 1983
OCTOBER 1984
OCTOBER 1985
OCTOBER 1986
OCTOBER 1987
OCTOBER 1988
OCTOBER 1989
OCTOBER 1990
YELLOW 1 Thickest Layer of Ozone
GREEN 2 Thick Layer of Ozone
BLUE 3 Thin Layer of Ozone
PURPLE 4 Thinnest Layer of Ozone

☛ Case No. 3 Why are scientists concerned about thinning of the ozone layer?

CLUES:



Ozone protects plant and animal life by absorbing much of the Sun's UV radiation. Scientists are not quite sure what will happen if the ozone layer becomes thin all over the planet, but because they know the harmful effects of short-wavelength UV radiation on living things, they are concerned. Even a hole over the Antarctic could have serious results. The cold oceans of the Antarctic are filled with one-celled algae called **phytoplankton**, a name that means "drifting plant." Surprisingly enough, all life in the world's oceans depends on these tiny plants. Through the process of photosynthesis, phytoplankton convert carbon dioxide and water into carbohydrates, fats, and proteins. If they are destroyed by UV radiation, the entire ocean **food web**, a whole system of **food chains**, would be upset. Also, scientists believe that these tiny plants remove about half the carbon dioxide entering the atmosphere. More carbon dioxide in the atmosphere could raise the temperature in Earth's greenhouse. This would affect all life on Earth, too.

Investigation A: Itty Bitty Swimming Things

Phytoplankton are at the bottom, or beginning, of a food chain. They are **producers**, creating their own food using the Sun's energy and nutrients in the water. They are eaten by small animals, which are in turn eaten by larger and larger animals. Eventually, the largest animals die and are broken down into nutrients by **decomposers**. The producers then use these same nutrients to create food, and the whole process continues. Scientists can guess what will happen if phytoplankton are exposed to too much UV radiation. No conclusive research has yet been done on the effect of UV radiation on decomposers. In this investigation, you will be able to look at some common decomposers.

Materials Needed

- ✓ **1 ℓ of tap water, or pond water if available**
- ✓ **dried grass or hay**
- ✓ **medicine dropper**
- ✓ **glass slides**
- ✓ **1-ℓ glass jar**
- ✓ **microscope**

Procedure

(If using tap water, allow it to age in an open container for several days.) Pour the water into the small jar to within about 2.5 cm of the top. Add a small handful of grass or hay to the water and cover the jar loosely. Allow it to sit for about 1 week out of direct sunlight. Using the medicine dropper, take a few drops from near the top of the water's surface. Place the drops on the slide and examine them under the microscope. Sketch what you see. These are **protozoa**, single-celled creatures that have both plant and animal characteristics. These protozoa are decomposers.

Questions

❶ Why should the tap water be aged?

❷ Where did the protozoa come from?

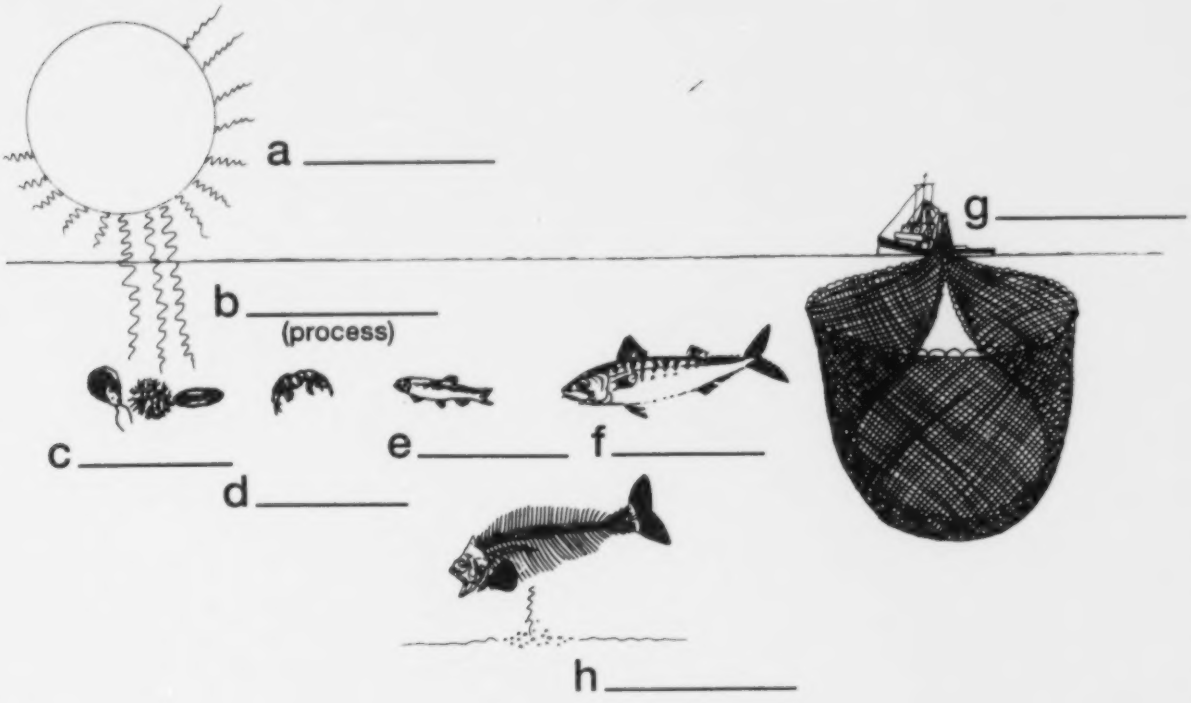
Investigation B: Food — Beginnings and Endings

Below is a word bank listing some of the elements and events in an ocean food chain:

Sun	people	**zooplankton**	phytoplankton
sardines	tuna	decomposers	photosynthesis

Procedure

Using the terms in the word bank, correctly identify each element in the illustrated food chain.



Questions

1. Briefly describe the process of photosynthesis.

2. What are the producers in this food chain?

3. What organism is at the top of this food chain?

4. When fish or plankton die and sink to the bottom, what organisms break down their bodies?

Investigator's Notebook: Kilogram for Kilogram

How much do you weigh? Because humans are consumers in a food web, every kilogram of our bodies was built out of nutrients from other plants and animals. Scientists estimate that the **ratio** is about 1 to 10 (1:10). This means that to make 1 kg of your weight, your body required about 10 kg of nutrients. Those 10 kg were made from 10 times that amount of the next item in the food chain.

If you had been raised on a diet of seafood, this is the number of kilograms it might have taken to reach your present weight:

_____ **kg your weight** $\xrightarrow{x10}$ _____ **kg shrimp** $\xrightarrow{x10}$ _____ **kg larvae** $\xrightarrow{x10}$ _____ **kg phytoplankton**

Try the same exercise with a beef diet:

_____ **kg your weight** $\xrightarrow{x10}$ _____ **kg beef** $\xrightarrow{x10}$ _____ **kg grain**

And with a vegetarian diet:

_____ **kg your weight** $\xrightarrow{x10}$ _____ **kg corn or rice**

Questions

❶ Can you calculate how much plankton a 130-metric-ton whale had to eat to reach its weight? (They are next to each other on the food chain.)

❷ What does this tell you about the importance of the tiny plankton?

❸ Why would it be a serious problem if too much UV light damaged the plankton?

Relating Science to . . .

Creative Writing: Every living creature has a vital function in nature's plan. Decomposers, like the ones investigated above, break down dead matter. What do you think would happen if decomposers like these were killed off or damaged by UV radiation? Write a story about a small pond, filled with turtles, fish, and plants, that suddenly loses its decomposers.

Helping Mother Earth

Take a class poll: How many students in your class drink at least one aluminum can of soda or juice every day? Did you know that if only 0.1 percent of the people in the U.S. recycled just one can a day, we could save the energy equivalent of over 13 million liters of gas per day? Extend the poll to the rest of your school.

Answers: The Crime

CASE #1 ANSWERS

Investigation A

❶ Yes, there is a temperature difference. ❷ Plastic wrap allows warming rays through and traps heat. ❸ Individual answers: both glass and atmosphere allow light through (you can see through them); both trap heat; other answers. ❹ Individual answers: glass is dense; atmosphere is not. **Note to Teacher:** Students may say glass is solid; use this to lead to discussion of density. Encourage discussion of the fact that both are made of molecules, but molecules of glass are much more dense. ❺ Closed, parked cars will be very hot. ❻ No.

Investigation B

❶ It absorbs heat. ❷ Individual answers: they wilt, collapse, die, dry out, "cook." ❸ Too much heat was absorbed. ❹ Animals could not withstand intense heat. **Note to Teacher:** Lead to discussion of balance or equilibrium. Plants and animals need just the right amount of heat: not too much, not too little. If nature or humans disturb the equilibrium, living creatures are harmed.

Investigator's Notebook

❶ Answers will depend on the region of the U.S. in which students are living. ❷ Answers should be 2 to 9 °C higher than current temperatures.

Relating Science to . . .

Creative Writing: Encourage students to spend some time imagining before they write.

Social Studies: Student research.

History: The Industrial Revolution began in the late 1700s; most historians set the dates as 1790 to 1850. Manufacturing of items such as clothing and shoes, which had once been done in homes, was now done in factories. Machines began to be used for farming, and factories now built those machines. The major source of power was coal. Some water power was used. **Note to Teacher:** Students should be helped to see the link between the use of fossil fuels for power and the increase of carbon dioxide.

CASE #2 ANSWERS

Investigation A

❶ Moisture collects at the top of the greenhouse. ❷ Because the heat rises and the water vapor is carried to the top. There it condenses against the plastic, which is cooled by outside air. ❸ The seedling could wilt and die. ❹ Earth's plants and animals would not do well in a too-warm environment.

Investigation B

No. If students do not reach a negative conclusion here, point out the number of particles contained in the rest of the atmosphere.

Investigator's Notebook

❶ The size of the areas rich in ozone appears to be decreasing. ❷ From space, scientists can measure the atmosphere in a number of places; they can also take measurements high above Earth. If measurements are performed over a long period of time, comparisons can be made, and potential problems and changes can be identified.

CASE #3 ANSWERS

Investigation A

❶ **Note to Teacher:** Give students time to think about this. Ask: Was there something in the water that would inhibit growth of protozoa? What do we put in our drinking water to kill bacteria? **Answer:** Chlorine. Chlorine would inhibit growth of protozoa. Aging allows chlorine to dissipate.

❷ Protozoa were on the grass or hay.

Investigation B

Procedure

(a) Sun **(b)** photosynthesis **(c)** phytoplankton **(d)** zooplankton **(e)** sardines **(f)** tuna **(g)** people **(h)** decomposers

Questions

❶ In photosynthesis, green plants use chlorophyll and light to transform water and carbon dioxide into food in the form of glucose (sugar). Oxygen and more water are also produced. ❷ Phytoplankton ❸ People ❹ Decomposers

Investigator's Notebook

Answers will depend on students' weights. **Note to Teacher:** Students probably know their weights in pounds. Have them convert to kilograms first. **(1)** A 130-metric-ton whale would have to have eaten 1,300 metric tons of plankton to reach its weight. **(2)** Individual answers. Encourage students to see the importance of plankton. **(3)** Entire food webs would be affected.

Relating Science to . . .

Note to Teacher: Be sure to have students formulate hypotheses before they begin. This is fairly new research. Answers are not known.

Investigation A: Building Gases

Scientists working on ATLAS 2 measure many familiar gases in the atmosphere, such as ozone, carbon monoxide, carbon dioxide, water vapor, and methane. They also measure less well-known gases such as chlorine monoxide and nitrogen compounds.

To understand the importance of these gases in the atmosphere, you must first know something about the structure of the molecules and atoms that make up these gases. Atoms, originally thought to be the smallest particles making up an element, are actually composed of **protons**, **neutrons**, and **electrons**. Protons are particles carrying a positive electric charge (+), and neutrons have no electric charge. Protons and neutrons form the **nucleus**, or center, of the atom. Electrons, which carry a negative charge (–), revolve around the nucleus in a kind of **electron cloud**. Low- energy electrons move around close to the nucleus, while high-energy electrons speed around the outside levels of the cloud. These levels are sometimes called **shells**.

Atoms can gain, lose, or share electrons. When atoms share electrons, **bonds** form between them, and they become molecules. Molecules may be composed of atoms from the same element or atoms from different elements. For example, oxygen molecules (O_2) are made of 2 atoms of oxygen, but water molecules (H_2O) are made of 2 atoms of hydrogen and 1 atom of oxygen. The small number to the right of the chemical symbol tells how many atoms of each element are in the molecule.

Atoms of oxygen (O) tend to gain electrons. They may also share electrons with other oxygen atoms, forming molecules of oxygen (O_2) or ozone (O_3). In the stratosphere, ozone protects plant and animal life by absorbing harmful ultraviolet (UV) rays. In the troposphere, ozone is not so helpful. It is a major ingredient in smog, which damages plants and endangers humans and other animals. Try making this model to help you visualize the formation of ozone, this gas that can be helpful or harmful.

Materials Needed:

- ✓ **4 white marshmallows**
- ✓ **toothpicks**

Procedure

The marshmallows represent atoms of oxygen, and the toothpicks represent the bonds between them. Use one toothpick to join two marshmallows. Repeat the process with the other two marshmallows. You now have a model of two molecules of O_2 as it usually exists in the lower atmosphere.

In the stratosphere, UV radiation is absorbed by O_2 molecules. This extra energy breaks the bond between the two atoms. Pull apart one pair of atoms to show the breaking of the bond. These oxygen atoms are now free to join with other O_2 molecules, forming O_3, or ozone. If you join one free marshmallow to a pair, you will have a model of O_3 and can see that there is still another oxygen atom ready to create more ozone.

Questions

❶ What do you think happens to the amount of UV radiation reaching Earth when ozone is destroyed?

Helping Mother Earth

Trees take in carbon dioxide, one of the major greenhouse gases, and use it and water to make food (a form of sugar). In return, they give us the oxygen we breathe. To help reduce greenhouse gases, it is important that we cut down fewer trees. To accomplish that, we must use less paper. Help your family start a "rag bag." In it, collect old clothes that can be used to clean up around the house, washed, and used again. This will save paper towels for "throw away" messes only.

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Investigation B: Out Goes the Ozone

Chlorofluorocarbons (CFCs) are compounds used mainly as coolants in refrigerators and air conditioners. When CFCs escape, they are mixed by air motions in the atmosphere and transported into the stratosphere. There, they absorb UV radiation. This extra energy breaks the bonds holding these compounds together, releasing an atom of chlorine. The chlorine atom then pulls away the third oxygen atom in ozone, breaking the weak bond that joins it to the rest of the molecule. This destroys an ozone molecule and forms a molecule containing one atom each of chlorine and oxygen that also has weak bonds, making it **unstable**.

Because the chlorine-oxygen molecule is unstable, it is easy for free atoms of oxygen (O) to pull away the oxygen atom, forming O_2 and releasing the chlorine to destroy more ozone. This process and slightly more complicated ones are what is depleting the protective "ozone umbrella" in the stratosphere. The chlorine is not used up, and it can continue to destroy ozone.

Make these models for a "bite-size" view of the reactions between CFCs and ozone.

Materials Needed:

- ✓ **bag of jellybeans, gumdrops, or other soft, multicolored candy**
- ✓ **box of toothpicks**

Procedure

One of the simplest CFC molecules is $CFCl_3$. It has one atom of carbon, one atom of fluorine, and three atoms of chlorine. To make a model of a molecule of $CFCl_3$, use three pieces of green candy to represent chlorine, one black piece to represent carbon, and one red piece to represent fluorine. Because the fluorine and carbon atoms are smaller than the chlorines, cut the black and red candies in half, and keep only half of each. Toothpicks will represent the bonds between the molecules.

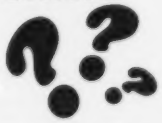
Stick three toothpicks into the piece of black candy, forming a three-legged stool with the legs evenly spread. Attach a green candy to the free end of each toothpick. Stand the stool on the desk and gently push down on the piece of black candy until the green pieces have slid apart enough that the black candy is suspended about 2 inches above the table. With your stool sitting on the table, insert a toothpick vertically in the top of the black candy and attach the red piece to the free end of the toothpick. This is a rough model of a $CFCl_3$ molecule. Lay it aside until later.

Use three pieces of white candy (representing atoms of oxygen) to create a model of ozone. Use two toothpicks to connect them, forming a triangle. Get an extra white piece and keep it handy for use later.

Lay your model of $CFCl_3$ and your model of ozone on a sheet of clean paper. When UV radiation hits a CFC molecule, the molecule releases chlorine. Pull off one green piece of candy from the $CFCl_3$ model to show this process.

The free chlorine atom destroys an ozone molecule by attracting one of the oxygen atoms away from the ozone molecule. Remove one of the white pieces of candy and its toothpick, and attach it to the free chlorine. This newly formed molecule containing chlorine and oxygen is unstable. Use the extra white candy to represent a free atom of oxygen. This can attract the other oxygen atom away from the chlorine. Remove the white candy and its toothpick from the green piece of candy and connect it to the "free" white piece.

Questions



1. At the end of this process, is the chlorine atom attached to anything?
2. If this chlorine atom gets near more ozone, what will happen?
3. What good things can you do now with all these candies?

Relating Science to . . .

Math: In 1991, the size of the Antarctic ozone hole was estimated at 17.58 million square km at its largest. This was 13 times its size 10 years ago. How large was it 10 years ago?

Common Questions About Ozone

REPRINTED FROM

"Scientific Assessment of Ozone Depletion: 1994"

WORLD METEOROLOGICAL ORGANIZATION
(GLOBAL OZONE RESEARCH AND MONITORING PROJECT—REPORT NO. 37)

National Oceanic and Atmospheric Administration
National Aeronautics and Space Administration
United Nations Environment Programme
World Meteorological Organization

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COMMON QUESTIONS ABOUT OZONE

Ozone is exceedingly rare in our atmosphere, averaging about 3 molecules of ozone for every ten million air molecules. Nonetheless, atmospheric ozone plays vital roles that belie its small numbers. This Appendix to the *World Meteorological Organization/United Nations Environment Programme (WMO/UNEP) Scientific Assessment of Ozone Depletion: 1994* (see p. 11) answers some of the questions that are most commonly asked about ozone and the changes that have been occurring in recent years. These common questions and their answers were discussed by the 80 scientists from 26 countries who participated in the Panel Review Meeting of the *Scientific Assessment of Ozone Depletion: 1994*. Therefore, this information is presented by a large group of experts from the international scientific community.

Ozone is mainly found in two regions of the Earth's atmosphere. Most ozone (about 90%) resides in a layer between approximately 10 and 50 kilometers (about 6 to 30 miles) above the Earth's surface, in the region of the atmosphere called the stratosphere. This stratospheric ozone is commonly known as the "ozone layer." The remaining ozone is in the lower region of the atmosphere, the troposphere, which extends from the Earth's surface up to about 10 kilometers. The figure below shows this distribution of ozone in the atmosphere.

While the ozone in these two regions is chemically identical (both consist of three oxygen atoms and have the chemical formula "O_3"), the ozone molecules have very different effects on humans and other living things depending upon their location.

Stratospheric ozone plays a beneficial role by absorbing most of the biologically damaging ultraviolet sunlight called UV-B, allowing only a small amount to reach the Earth's surface. The absorption of UV radiation by ozone creates a source of heat, which actually forms the stratosphere itself (a region in which the temperature rises as one goes to higher altitudes). Ozone thus plays a key role in the temperature structure of the Earth's atmosphere. Furthermore, without the filtering action of the ozone layer, more of the Sun's UV-B radiation would penetrate the atmosphere and would reach the Earth's surface in greater amounts. Many experimental studies of plants and animals, and clinical studies of humans, have shown the harmful effects of excessive exposure to UV-B radiation (these are discussed in the WMO/UNEP reports on impacts of ozone depletion, which are companion documents to the WMO/UNEP scientific assessments of ozone depletion).

At the planet's surface, ozone comes into direct contact with life-forms and displays its destructive side. Because ozone reacts strongly with other molecules, high levels are toxic to living systems and can severely damage the tissues of plants and animals. Many studies have documented the harmful effects of ozone on crop production, forest growth, and human health. The substantial negative effects of surface-level tropospheric ozone from this direct toxicity contrast with the benefits of the additional filtering of UV-B radiation that it provides.

With these dual aspects of ozone come two separate environmental issues, controlled by different forces in the atmosphere. In the troposphere, there is concern about *increases* in ozone. Low-lying ozone is a key component of smog, a familiar problem in the atmosphere of many cities around the world. Higher than usual amounts of surface-level ozone are now increasingly being observed in rural areas as well. However, the ground-level ozone concentrations in the smoggiest cities are very much smaller than the concentrations routinely found in the stratosphere.

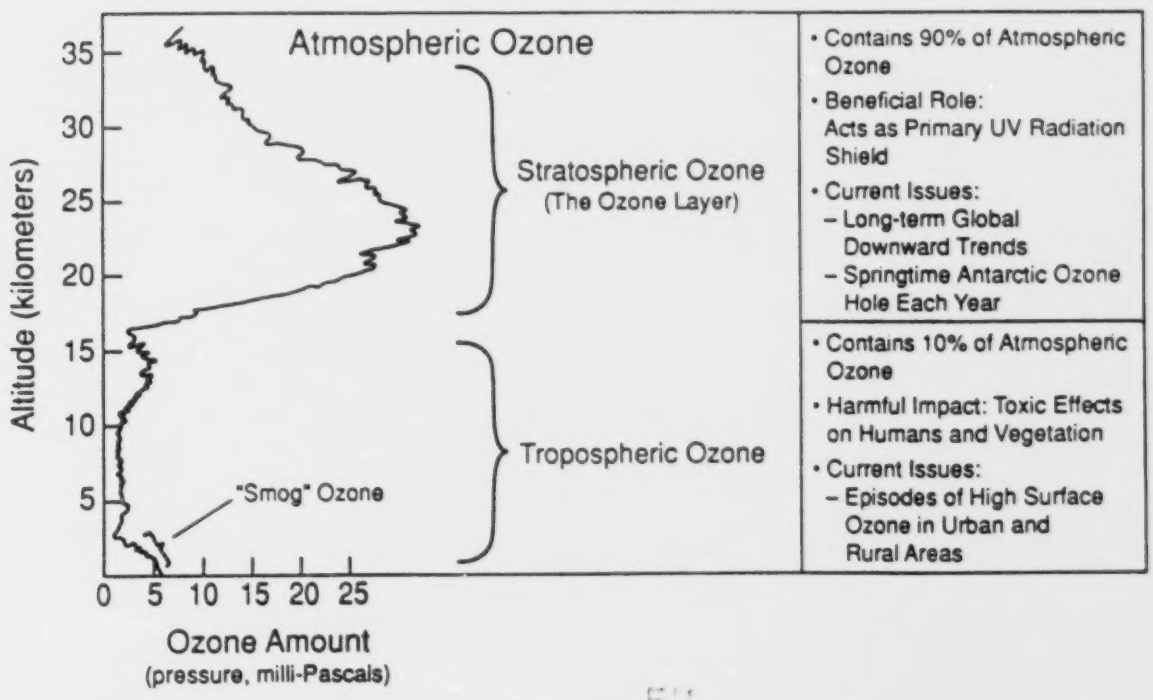
There is widespread scientific and public interest and concern about *losses* of stratospheric ozone. Ground-based and satellite instruments have measured decreases in the amount of stratospheric ozone in our atmosphere. Over some parts of Antarctica, up to 60% of the total overhead amount of ozone (known as the "column ozone") is depleted during September and October. This phenomenon has come to be known as the Antarctic "ozone hole." Smaller, but still significant, stratospheric decreases have been seen at other, more-populated regions of the Earth. Increases in surface UV-B radiation have been observed in association with decreases in stratospheric ozone.

The scientific evidence, accumulated over more than two decades of study by the international research community, has shown that human-made chemicals are responsible for the observed

depletions of the ozone layer over Antarctica and likely play a major role in global ozone losses. The ozone-depleting compounds contain various combinations of the chemical elements chlorine, fluorine, bromine, carbon, and hydrogen, and are often described by the general term *halocarbons*. The compounds that contain only carbon, chlorine, and fluorine are called *chlorofluorocarbons*, usually abbreviated as *CFCs*. CFCs, carbon tetrachloride, and methyl chloroform are important human-made ozone-depleting gases that have been used in many applications including refrigeration, air conditioning, foam blowing, cleaning of electronics components, and as solvents. Another important group of human-made halocarbons is the *halons*, which contain carbon, bromine, fluorine, and (in some cases) chlorine, and have been mainly used as fire extinguishants. Governments have decided to discontinue production of CFCs, halons, carbon tetrachloride, and methyl chloroform, and industry has developed more "ozone-friendly" substitutes.

Two responses are natural when a new problem has been identified: cure and prevention. When the problem is the destruction of the stratospheric ozone layer, the corresponding questions are: Can we repair the damage already done? How can we prevent further destruction? Remedies have been investigated that could (i) remove CFCs selectively from our atmosphere, (ii) intercept ozone-depleting chlorine before much depletion has taken place, or (iii) replace the ozone lost in the stratosphere (perhaps by shipping the ozone from cities that have too much smog or by making new ozone). Because ozone reacts strongly with other molecules, as noted above, it is too unstable to be made elsewhere (e.g., in the smog of cities) and transported to the stratosphere. When the huge volume of the Earth's atmosphere and the magnitude of global stratospheric ozone depletion are carefully considered, approaches to cures quickly become much too expensive, impractical, and potentially damaging to the global environment. Prevention involves the internationally agreed-upon Montreal Protocol and its Amendments and Adjustments, which call for elimination of the production and use of the CFCs and other ozone-damaging compounds within the next few years. As a result, the ozone layer is expected to recover over the next fifty years or so as the atmospheric concentrations of CFCs and other ozone-depleting compounds slowly decay.

The current understanding of ozone depletion and its relation to humankind is discussed in detail by the leading scientists in the world's ozone research community in the *Scientific Assessment of Ozone Depletion: 1994*. The answers to the common questions posed below are based upon that understanding and on the information given in earlier WMO/UNEP reports.

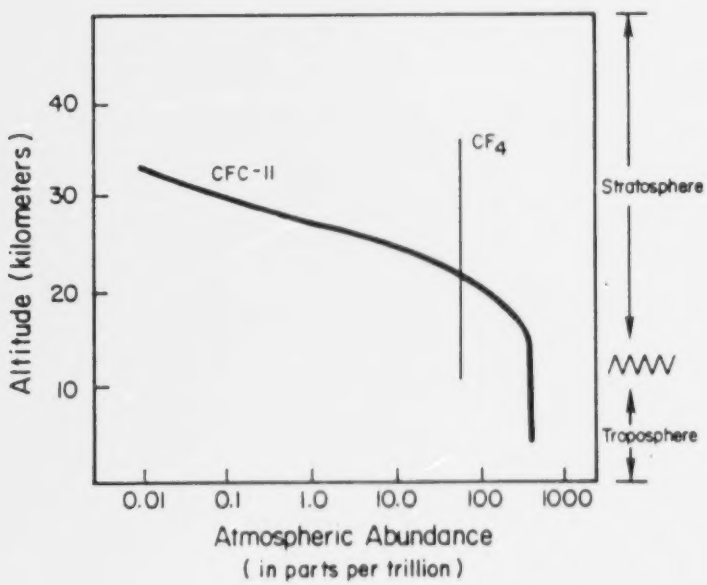


How Can Chlorofluorocarbons (CFCs) Get to the Stratosphere If They're Heavier than Air?

Although the CFC molecules are indeed several times heavier than air, thousands of measurements have been made from balloons, aircraft, and satellites demonstrating that the CFCs are actually present in the stratosphere. The atmosphere is not stagnant. Winds mix the atmosphere to altitudes far above the top of the stratosphere much faster than molecules can settle according to their weight. Gases such as CFCs that are insoluble in water and relatively unreactive in the lower atmosphere (below about 10 km) are quickly mixed and therefore reach the stratosphere regardless of their weight.

Much can be learned about the atmospheric fate of compounds from the measured changes in concentration versus altitude. For example, the two gases carbon tetrafluoride (CF_4, produced mainly as a by-product of the manufacture of aluminum) and CFC-11 (CCl_3F, used in a variety of human activities) are both much heavier than air. Carbon tetrafluoride is completely unreactive in the lower 99.9% of the atmosphere, and measurements show it to be nearly uniformly distributed throughout the atmosphere as shown in the figure. There have also been measurements over the past two decades of several other completely unreactive gases, one lighter than air (neon) and some heavier than air (argon, krypton), which show that they also mix upward uniformly through the stratosphere regardless of their weight, just as observed with carbon tetrafluoride. CFC-11 is unreactive in the lower atmosphere (below about 15 km) and is similarly uniformly mixed there, as shown. The abundance of CFC-11 decreases as the gas reaches higher altitudes, where it is broken down by high energy solar ultraviolet radiation. Chlorine released from this breakdown of CFC-11 and other CFCs remains in the stratosphere for several years, where it destroys many thousands of molecules of ozone.

Measurements of CFC-11 and CF_4



What is the Evidence that Stratospheric Ozone is Destroyed by Chlorine and Bromine?

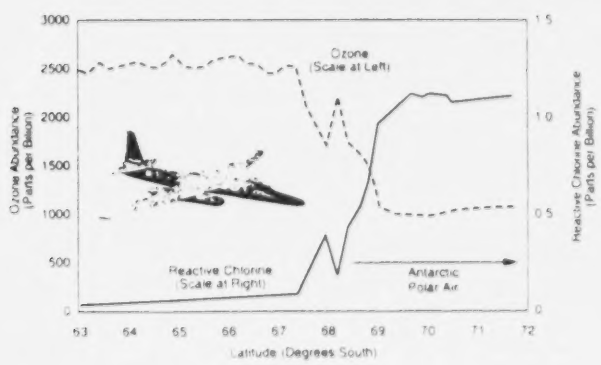
Laboratory studies show that chlorine (Cl) reacts very rapidly with ozone. They also show that the reactive chemical chlorine oxide (ClO) formed in that reaction can undergo further processes which regenerate the original chlorine, allowing the sequence to be repeated very many times (a "chain reaction"). Similar reactions also take place between bromine and ozone.

But do these ozone-destroying reactions occur in the real world? All of our accumulated scientific experience demonstrates that if the conditions of temperature and pressure are like those in the laboratory studies, the same chemical reactions will take place in nature. However, many other reactions including those of other chemical species are often also taking place simultaneously in the stratosphere, making the connections among the changes difficult to untangle. Nevertheless, whenever chlorine (or bromine) and ozone are found together in the stratosphere, the ozone-destroying reactions must be taking place.

Sometimes a small number of chemical reactions is so important in the natural circumstance that the connections are almost as clear as in laboratory experiments. Such a situation occurs in the Antarctic stratosphere during the springtime formation of the ozone hole. During August and September 1987 – the end of winter and beginning of spring in the Southern Hemisphere – aircraft equipped with many different instruments for measuring a large number of chemical species were flown repeatedly over Antarctica. Among the chemicals measured were ozone and chlorine oxide, the reactive chemical identified in the laboratory as one of the participants in the ozone-destroying chain reactions. On the first flights southward from the southern tip of South America, relatively high concentrations of ozone were measured everywhere over Antarctica. By mid-September, however, the instruments recorded low concentrations of ozone in regions where there were high concentrations of chlorine oxide and vice versa, as shown in the figure. Flights later in September showed even less ozone over Antarctica, as the chlorine continued to react with the stratospheric ozone.

Independent measurements made by these and other instruments on this and other airplanes, from the ground, from balloons, and from satellites have provided a detailed understanding of the chemical reactions going on in the Antarctic stratosphere. Regions with high concentrations of reactive chlorine reach temperatures so cold (less than approximately -80°C, or -112°F) that stratospheric clouds form, a rare occurrence except during the polar winters. These clouds facilitate other chemical reactions that allow the release of chlorine in sunlight. The chemical reactions related to the clouds are now well understood through study under laboratory conditions mimicking those found naturally. Scientists are working to understand the role of such reactions of chlorine and bromine at other latitudes, and the involvement of particles of sulfuric acid from volcanoes or other sources.

Measurements of Ozone and Reactive Chlorine from a Flight into the Antarctic Ozone Hole



Does Most of the Chlorine in the Stratosphere Come from Human or Natural Sources?

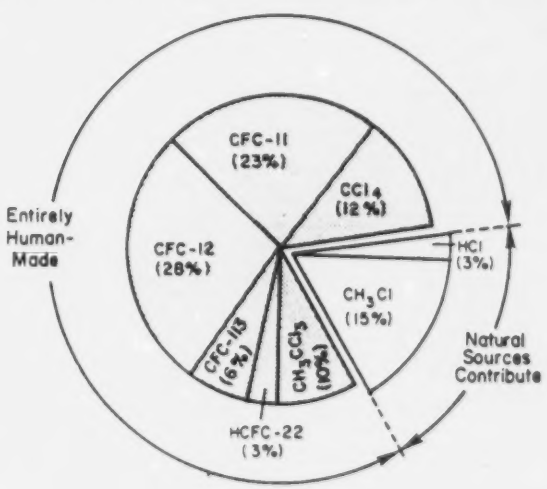
Most of the chlorine in the stratosphere is there as a result of human activities.

Many compounds containing chlorine are released at the ground, but those that dissolve in water cannot reach stratospheric altitudes. Large quantities of chlorine are released from evaporated ocean spray as sea salt (sodium chloride) aerosol. However, because sea salt dissolves in water, this chlorine quickly is taken up in clouds or in ice, snow, or rain droplets and does not reach the stratosphere. Another ground-level source of chlorine is its use in swimming pools and as household bleach. When released, this chlorine is rapidly converted to forms that dissolve in water and therefore are removed from the lower atmosphere, never reaching the stratosphere in significant amounts. Volcanoes can emit large quantities of hydrogen chloride, but this gas is rapidly converted to hydrochloric acid in rain water, ice, and snow and does not reach the stratosphere. Even in explosive volcanic plumes that rise high in the atmosphere, nearly all of the hydrogen chloride is scrubbed out in precipitation before reaching stratospheric altitudes.

In contrast, human-made halocarbons – such as CFCs, carbon tetrachloride (CCl_4) and methyl chloroform (CH_3CCl_3) – are not soluble in water, do not react with snow or other natural surfaces, and are not broken down chemically in the lower atmosphere. While the exhaust from the Space Shuttle and from some rockets does inject some chlorine directly into the stratosphere, this input is very small (less than one percent of the annual input from halocarbons in the present stratosphere, assuming nine Space Shuttle and six Titan IV rocket launches per year).

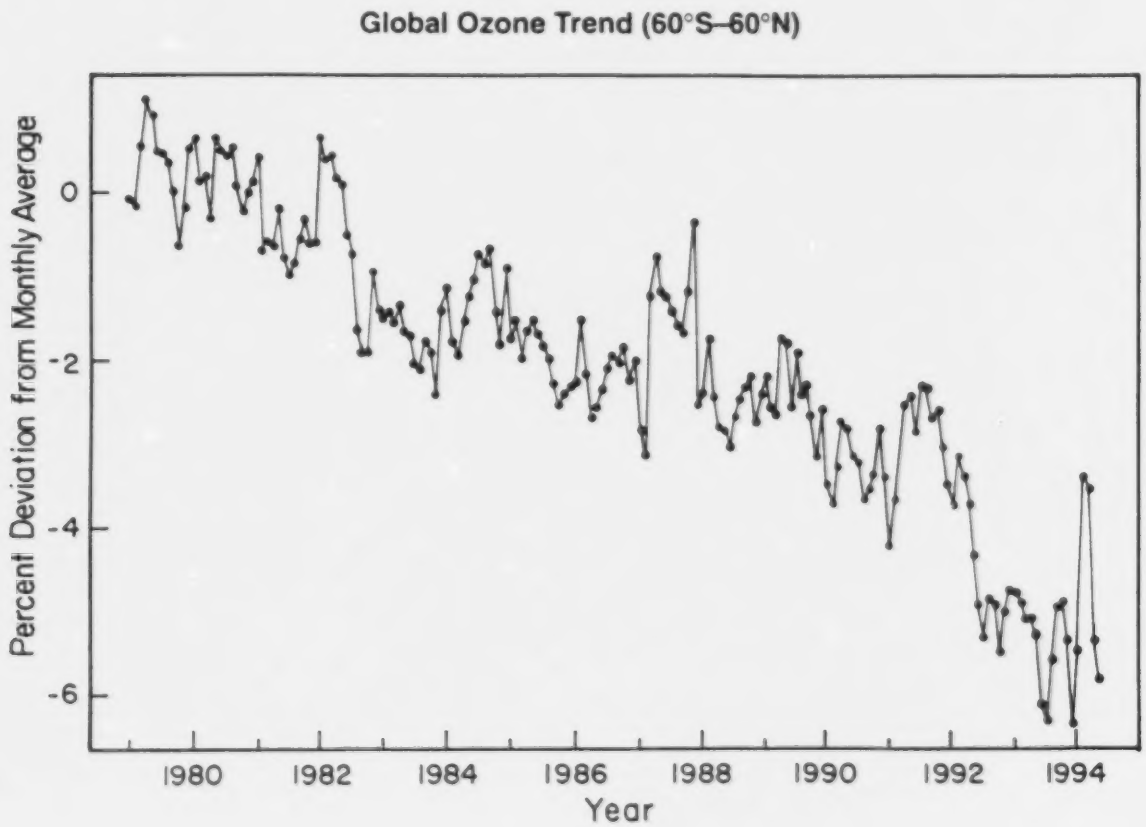
Several pieces of evidence combine to establish human-made halocarbons as the primary source of stratospheric chlorine. First, measurements (see the figure below) have shown that the chlorinated species that rise to the stratosphere are primarily manufactured compounds (mainly CFCs, carbon tetrachloride, methyl chloroform, and the HCFC substitutes for CFCs), together with small amounts of hydrochloric acid (HCl) and methyl chloride (CH_3Cl) which are partly natural in origin. The natural contribution now is much smaller than that from human activities, as shown in the figure below. Second, in 1985 and 1992 researchers measured nearly all known gases containing chlorine in the stratosphere. They found that human emissions of halocarbons plus the much smaller contribution from natural sources could account for all of the stratospheric chlorine compounds. Third, the *increase* in total stratospheric chlorine measured between 1985 and 1992 corresponds with the known increases in concentrations of human-made halocarbons during that time.

Primary Sources of Chlorine Entering the Stratosphere



Can Changes in the Sun's Output Be Responsible for the Observed Changes in Ozone?

Stratospheric ozone is primarily created by ultraviolet (UV) light coming from the Sun, so the Sun's output affects the rate at which ozone is produced. The Sun's energy release (both as UV light and as charged particles such as electrons and protons) does vary, especially over the well-known 11-year sunspot cycle. Observations over several solar cycles (since the 1960s) show that total global ozone levels decrease by 1-2% from the maximum to the minimum of a typical cycle. Changes in the Sun's output cannot be responsible for the observed long-term changes in ozone, because these downward trends are much larger than 1-2%. Further, during the period since 1979, the Sun's energy output has gone from a maximum to a minimum in 1985 and back through another maximum in 1991, but the trend in ozone was downward throughout that time. The ozone trends presented in this and previous international scientific assessments have been obtained by evaluating the long-term changes in ozone concentrations after accounting for the solar influence (as has been done in the figure below).



When Did the Antarctic Ozone Hole First Appear?

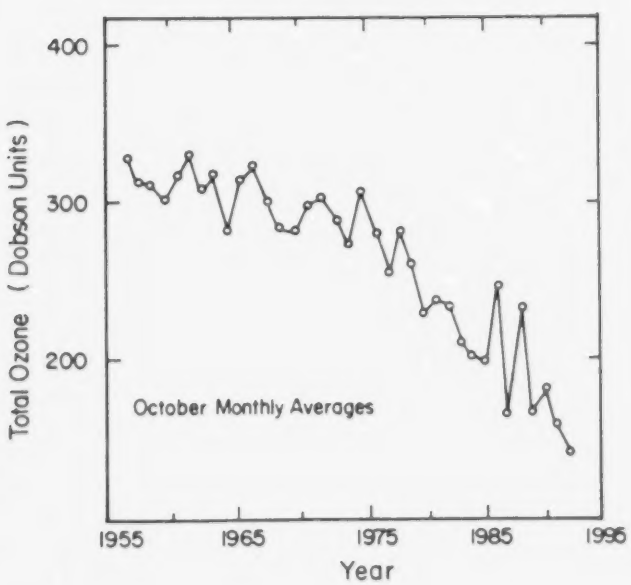
The Antarctic ozone hole is a new phenomenon. The figure shows that observed ozone over the British Antarctic Survey station at Halley Bay, Antarctica first revealed obvious decreases in the early 1980s compared to data obtained since 1957. The ozone hole is formed each year when there is a sharp decline (currently up to 60%) in the total ozone over most of Antarctica for a period of about two months during Southern Hemisphere spring (September and October). Observations from three other stations in Antarctica, also covering several decades, reveal similar progressive, recent decreases in springtime ozone. The ozone hole has been shown to result from destruction of stratospheric ozone by gases containing chlorine and bromine, whose sources are mainly human-made halocarbon gases.

Before the stratosphere was affected by human-made chlorine and bromine, the naturally occurring springtime ozone levels over Antarctica were about 30-40% lower than springtime ozone levels over the Arctic. This natural difference between Antarctic and Arctic conditions was first observed in the late 1950s by Dobson. It stems from the exceptionally cold temperatures and different winter wind patterns within the Antarctic stratosphere as compared to the Arctic. This is not at all the same phenomenon as the marked downward trend in total ozone in recent years referred to as the ozone hole and shown in the figure below.

Changes in stratospheric meteorology cannot explain the ozone hole. Measurements show that wintertime Antarctic stratospheric temperatures of past decades have not changed prior to the development of the hole each September. Ground, aircraft, and satellite measurements have provided, in contrast, clear evidence of the importance of the chemistry of chlorine and bromine originating from human-made compounds in depleting Antarctic ozone in recent years.

A single report of extremely low Antarctic winter ozone in one location in 1958 by an unproven technique has been shown to be completely inconsistent with the measurements depicted here and with all credible measurements of total ozone.

Historical Springtime Total Ozone Record for Halley Bay, Antarctica (76°S)



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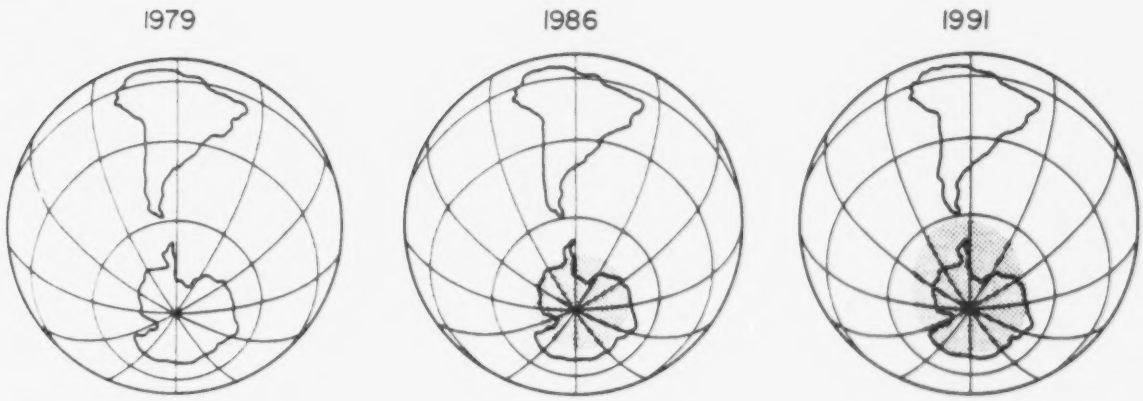
Why is the Ozone Hole Observed over Antarctica When CFCs Are Released Mainly in the Northern Hemisphere?

Human emissions of CFCs do occur mainly in the Northern Hemisphere, with about 90% released in the latitudes corresponding to Europe, Russia, Japan, and North America. Gases such as CFCs that are insoluble in water and relatively unreactive are mixed within a year or two throughout the lower atmosphere (below about 10 km). The CFCs in this well-mixed air rise from the lower atmosphere into the stratosphere mainly in tropical latitudes. Winds then move this air poleward – both north and south – from the tropics, so that air throughout the stratosphere contains nearly the same amount of chlorine. However, the meteorologies of the two polar regions are very different from each other because of major differences at the Earth's surface. The South Pole is part of a very large land mass (Antarctica) that is completely surrounded by ocean. These conditions produce very low stratospheric temperatures which in turn lead to formation of clouds (polar stratospheric clouds). The clouds that form at low temperatures lead to chemical changes that promote rapid ozone loss during September and October of each year, resulting in the ozone hole.

In contrast, the Earth's surface in the northern polar region lacks the land/ocean symmetry characteristic of the southern polar area. As a consequence, Arctic stratospheric air is generally much warmer than in the Antarctic, and fewer clouds form there. Therefore, the ozone depletion in the Arctic is much less than in the Antarctic.

Schematic of Antarctic Ozone Hole

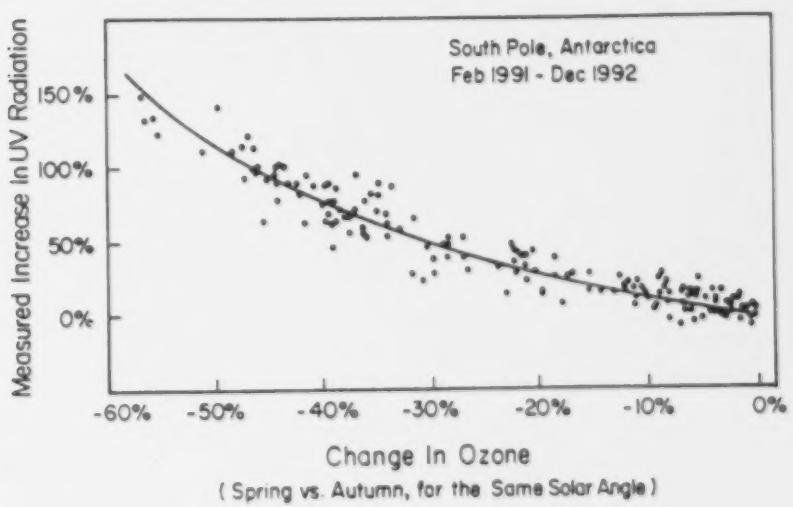


Is the Depletion of the Ozone Layer Leading to an Increase in Ground-Level Ultraviolet Radiation?

The Sun emits light over a wide range of energies, with about two percent given off in the form of high-energy, ultraviolet (UV) radiation. Some of this UV radiation (UV-B) is especially effective in causing damage to living things, including sunburn, skin cancer, and eye damage for humans. The amount of solar UV radiation received at any particular location on the Earth's surface depends upon the position of the Sun above the horizon, on the amount of ozone in the atmosphere, and upon local cloudiness and pollution. Scientists agree that in the absence of changes in clouds or pollution, decreases in atmospheric ozone will increase ground-level UV radiation.

The largest decreases in ozone during the last decade have been observed over Antarctica, especially during each September and October when the "ozone hole" forms. During the last several years, simultaneous measurements of UV radiation and total ozone have been made at several Antarctic stations. As shown in the figure below, when the ozone amounts decrease, UV-B increases. Because of the ozone hole, the UV-B intensity at Palmer Station, Antarctica, in late October, 1993, was more intense than found at San Diego, California, at any time during all of 1993. In areas where small ozone depletion has been observed, UV-B increases are more difficult to detect. Detection of UV trends associated with ozone decreases can also be complicated by changes in cloudiness or by local pollution, as well as by difficulties in keeping the detection instrument in precisely the same condition over many years. Prior to the late 1980s, instruments with the necessary accuracy and stability for measurement of small long-term trends in ground-level UV-B were not employed. Recently, however, such instruments have been used in the Antarctic because of the very large changes in ozone being observed there. When high-quality measurements have been made in other areas far from major cities and their associated air pollution, decreases in ozone have regularly been accompanied by increases in UV-B. The data from urban locations with older, less specialized instruments provide much less reliable information, especially because good simultaneous measurements are not available for any changes in cloudiness or local pollution.

Increases in Erythemal (Sunburning) UV Radiation Due to Ozone Reductions



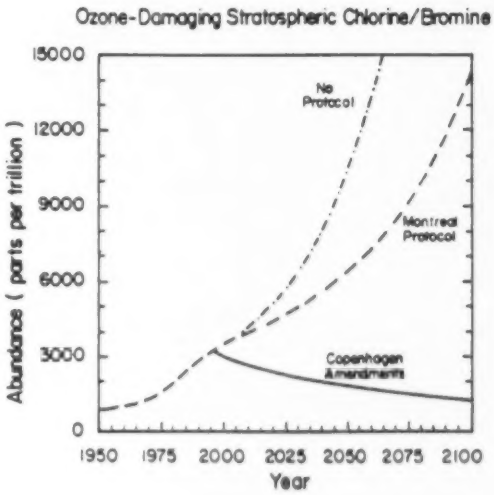
How Severe Is the Ozone Depletion Now, and Is It Expected to Get Worse?

Scientific evidence shows that ozone depletion caused by human-made chemicals is continuing and is expected to persist until chlorine and bromine levels are reduced. Worldwide monitoring has shown that stratospheric ozone has been decreasing for the past two decades or more. Globally averaged losses have totaled about 5% since the mid-1960s, with cumulative losses of about 10% in the winter and spring and 5% in the summer and autumn over locations such as Europe, North America, and Australia. Since the late-1970s, an ozone "hole" has formed in Antarctica each Southern Hemisphere spring (September / October), in which up to 60% of the total ozone is depleted. The large increase in atmospheric concentrations of human-made chlorine and bromine compounds is responsible for the formation of the Antarctic ozone hole, and the weight of evidence indicates that it also plays a major role in midlatitude ozone depletion.

During 1992 and 1993 ozone in many locations dropped to record low values: springtime depletions exceeded 20% in some populated northern midlatitude regions, and the levels in the Antarctic ozone hole fell to the lowest values ever recorded. The unusually large ozone decreases of 1992 and 1993 are believed to be related, in part, to the volcanic eruption of Mount Pinatubo in the Philippines during 1991. This eruption produced large amounts of stratospheric sulfate aerosols that temporarily increased the ozone depletion caused by human-made chlorine and bromine compounds. Recent observations have shown that as those aerosols have been swept out of the stratosphere, ozone concentrations have returned to the depleted levels consistent with the downward trend observed before the Mount Pinatubo eruption.

In 1987 the recognition of the potential for chlorine and bromine to destroy stratospheric ozone led to an international agreement (The United Nations Montreal Protocol on Substances that Deplete the Ozone Layer) to reduce the global production of ozone-depleting substances. Since then, new global observations of significant ozone depletion have prompted amendments to strengthen the treaty. The 1992 Copenhagen Amendments call for a ban on production of the most damaging compounds by 1996. The figure shows past and projected future stratospheric abundances of chlorine and bromine: (a) without the Protocol; (b) under the Protocol's original provisions; and (c) under the Copenhagen Amendments now in force. Without the Montreal Protocol and its Amendments, continuing human use of CFCs and other compounds would have tripled the stratospheric abundances of chlorine and bromine by about the year 2050. Current scientific understanding indicates that such increases would have led to global ozone depletion very much larger than observed today. In contrast, under current international agreements, which are now reducing and will eventually eliminate human emissions of ozone-depleting gases, the stratospheric abundances of chlorine and bromine are expected to reach their maximum within a few years and then slowly decline. All other things being equal, the ozone layer is expected to return to normal by the middle of the next century.

In summary, record low ozone levels have been observed in recent years, and substantially larger future global depletions in ozone would have been highly likely without reductions in human emissions of ozone-depleting gases. However, worldwide compliance with current international agreements is rapidly reducing the yearly emissions of these compounds. As these emissions cease, the ozone layer will gradually improve over the next several decades. The recovery of the ozone layer will be gradual because of the long times required for CFCs to be removed from the atmosphere.



About the *WMO/UNEP Scientific Assessment of Ozone Depletion: 1994* and the *Common Questions About Ozone*

These "Common Questions About Ozone" were prepared as a special section of the World Meteorological Organization/United Nations Environment Programme *Scientific Assessment of Ozone Depletion: 1994*. Dr. Susan Solomon, of the National Oceanic and Atmospheric Administration, and Dr. F. Sherwood Rowland, of the University of California at Irvine, coordinated their preparation based on the discussions of 80 international scientists at the *Assessment* Panel Review Meeting held in July of 1994. The answers reflect the scientific understanding presented in the *Assessment*, which was prepared and reviewed by 295 of the world's leading scientists.

The *Scientific Assessment of Ozone Depletion: 1994* is part of the information upon which the Parties to the United Nations Montreal Protocol will base their future decisions regarding protection of the stratospheric ozone layer. It is prepared in concordance with Article 6 of the Montreal Protocol on Substances That Deplete the Ozone Layer. The Parties to the Protocol will meet in Vienna during the Fall of 1995, at which time they will consider possible amendments to the Protocol based upon the findings of the 1994 *Assessment*.

The *Assessment* is available from the World Meteorological Organization, Global Ozone Observing System, P.O. Box 2300, 1211-Geneva-2, Switzerland.

"Common Questions About Ozone"

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EPA 430-F-95-003
JANUARY 1995

BE SUN WISE

HEALTH EFFECTS OF OVEREXPOSURE TO THE SUN

UV INDEX

Americans love the sun, and spend increasing amounts of time outside — working, playing, exercising — often in clothing that exposes a lot of skin to the sun. Most people are now aware that too much sun has been linked to skin cancer, but few know the degree of risk posed by overexposure, and fewer are aware that the risks go beyond skin cancer. Recent medical research has shown that overexposure to the sun's ultraviolet (UV) radiation can contribute to serious health problems.

This fact sheet provides a quick overview of the major problems linked to UV exposure: skin cancer (melanoma and non-melanoma), other skin problems, cataracts, and immune system suppression. Understanding these risks and taking a few sensible precautions (described in other UV Index fact sheets) will help you to enjoy the sun while lowering your chances of sun-related health problems later in life.

MELANOMA

Melanoma, the most serious form of skin cancer, is also one of the fastest growing types of cancer in the U.S. Many dermatologists believe that there may be a link between childhood sunburns and malignant melanoma later in life. Melanoma cases in this country have almost doubled in the past two decades, with at least 32,000 new cases of melanoma and 6,900 deaths estimated for 1994 alone. The rise in melanoma cases and deaths in America is expected to continue.

CURE RATE

Melanoma can spread to other parts of the body quickly, but when detected in its earliest stages it is almost always curable. If not caught early, melanoma is often fatal.

WHAT TO WATCH FOR

Melanoma begins as an uncontrolled growth of pigment-producing cells in the skin. This growth leads to the formation of dark-pigmented malignant moles or tumors, called melanomas. Melanomas may suddenly appear without warning, but may also develop from or near a mole. For that reason it is important to know the location and appearance of moles on the body so any change will be noticed. Melanomas are found most frequently on the upper backs of men and women, and the legs of women, but can occur anywhere on the body.

Be aware of any unusual skin condition, especially a change in the size or color of a mole or other darkly or irregularly pigmented growth or spot; scaliness, oozing, bleeding or change in the appearance of a bump or nodule; spread of pigment from the border into surrounding skin; and change in sensation including itchiness, tenderness, or pain.

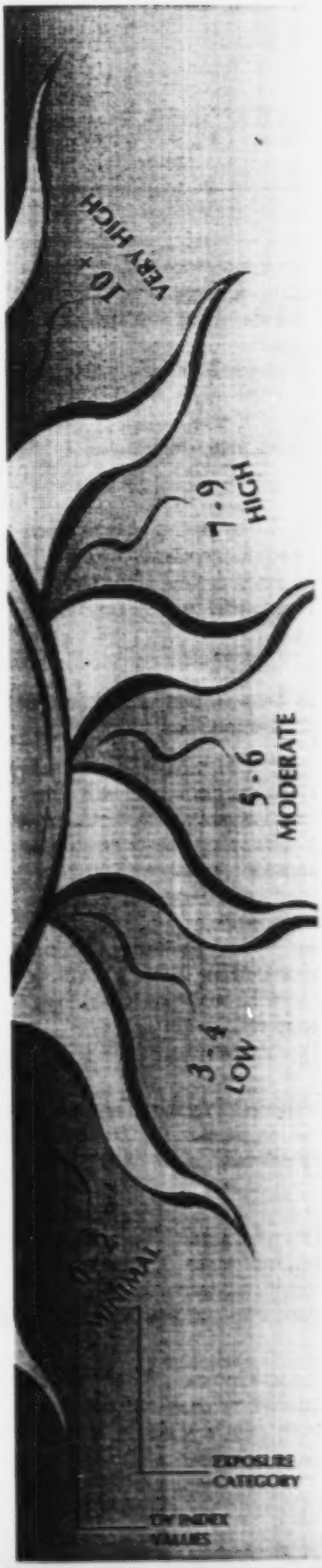
NON-MELANOMA SKIN CANCERS

Unlike melanoma, non-melanoma skin cancers are rarely fatal. Nevertheless, they should not be taken lightly. Untreated, they can spread, causing more serious health problems. An estimated 900,000 Americans developed non-melanoma skin cancers in 1994, while 1,200 died from the disease.

There are two primary types of non-melanoma skin cancers:

Basal Cell Carcinomas are tumors of the skin which usually appear as small, fleshy bumps or nodules on the head and neck, but can occur on other skin areas as well. It is the most common skin cancer found among fair-skinned people. Basal cell carcinoma does not grow quickly, and rarely spreads to other parts of the body. However, it can penetrate below the skin to the bone and cause considerable local damage.

Squamous Cell Carcinomas are tumors which may appear as nodules or as red, scaly patches. The second most common skin cancer found in fair-skinned people, squamous cell carcinoma is rarely found in darker-skinned people. This cancer can develop into large masses, and unlike basal cell carcinoma, it can spread to other parts of the body.



CURE RATE

These two non-melanoma skin cancers have high cure rates — as high as 95 percent if detected and treated early. The key is to watch for signs and to detect the cancer in its early stages.

WHAT TO WATCH FOR

Basal cell carcinoma tumors usually appear as slowly growing, raised, translucent, pearly nodules which, if untreated, may crust, discharge pus, and sometimes bleed. Squamous cell carcinomas usually are raised, red or pink scaly nodules or wart-like growths that form pus in the center. They typically develop on the edge of the ears, the face, lips, mouth, hands and other exposed areas of the body.

ACTINIC KERATOSES

These sun-induced skin growths occur on body areas exposed to the sun. The face, hands, forearms and the "V" of the neck are especially susceptible to this type of blemish. They are pre-malignant, but left untreated, actinic keratoses can become malignant. Look for raised, reddish, rough-textured growths. See a dermatologist promptly if you notice these growths.

PHOTOAGING

Chronic exposure to the sun causes changes in the skin called actinic, or solar, degeneration. The skin over time becomes thick, wrinkled, and leathery. This condition has often been referred to as "premature aging" of the skin. Since it occurs gradually, often manifesting itself many years after the majority of a person's exposure to the sun, photoaging is often regarded as an unavoidable condition, a normal part of growing older. With proper protection from UV radiation, however, photoaging can be substantially avoided.

CATARACTS AND OTHER EYE DAMAGE

Cataracts are a form of eye damage, a loss of transparency in the lens which clouds vision. Left untreated, cataracts can rob people of vision. Research has shown that UV radiation increases the likelihood of certain cataracts. Although curable with modern eye surgery, cataracts diminish the eyesight of millions of Americans, and necessitate millions of dollars of eye surgery each year. Other kinds of eye damage include: pterygium (tissue growth on the white of the eye that can block vision), skin cancer around the eyes, and degeneration of the macula (the part of the retina near the center, where visual perception is most acute). All of these problems could be lessened with proper eye protection from UV radiation.

IMMUNE SUPPRESSION

Scientists have found that sunburn can alter the distribution and function of disease-fighting white blood cells in humans for up to 24 hours after exposure to the sun. Repeated exposure to UV radiation may cause more long-lasting damage to the body's immune system. Mild sunburns can directly suppress the immune functions of human skin where the sunburn occurred, even in people with dark skin.

ABOUT THE UV INDEX...

The UV Index, developed by the National Weather Service and the Environmental Protection Agency, provides a forecast of the expected risk of overexposure to the sun and indicates the degree of caution you should take when working, playing, or exercising outdoors. The UV Index predicts exposure levels on a 0 - 10+ scale, where 0 indicates a low risk of overexposure, and 10+ means a very high risk of overexposure. Calculated on a next-day basis for dozens of cities across the U.S. by the National Weather Service, the UV Index takes into account clouds and other local conditions that affect the amount of UV radiation reaching the ground in different parts of the country.

FOR MORE INFORMATION

To learn more about the UV Index and how to protect yourself from overexposure to the sun's UV rays, call EPA's Stratospheric Ozone Hotline at (800) 296-1996. Hotline staff can supply you with other fact sheets in this series, as well as other useful information.

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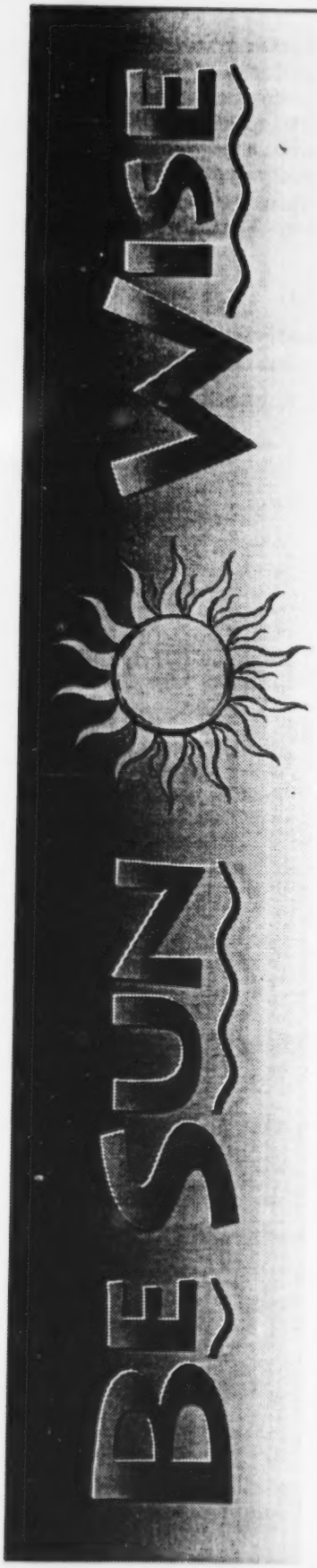


ACTION STEPS FOR SUN PROTECTION

TOO MUCH SUNLIGHT CAN BE DANGEROUS....

Being outside on a warm, sunny day is one of life's great pleasures, but getting too much sun can be dangerous. Excessive sun exposure can result in painful sunburn, but can also lead to other serious health problems, including melanoma, a life-threatening form of skin cancer. Melanoma is one of the fastest growing forms of cancer in the U.S. New melanoma cases in the U.S. have more than doubled over the past two decades, with an estimated 6,900 American deaths from the disease in 1994. In addition to melanoma, excessive UV exposure can lead to premature aging of the skin, cataracts, non-melanoma skin cancers, and immune system suppression.

BE SUN WISE

Protecting yourself from overexposure to UV radiation is simple:

WEAR SUNGLASSES THAT BLOCK 99-100% OF UV RADIATION

Sunglasses that provide 99-100% UVA and UVB protection will greatly reduce sun exposure that can lead to cataracts and other eye damage. Check the label when buying sunglasses.

WEAR A HAT

A hat with a wide brim offers good sun protection to your eyes, ears, face, and the back of your neck — areas particularly prone to overexposure to the sun.

PROTECT OTHER AREAS OF YOUR BODY WITH CLOTHING DURING PROLONGED PERIODS IN THE SUN

Tightly-woven, loose-fitting clothes are best, but any clothing is better than none at all.

ALWAYS USE A SUNSCREEN WHEN OUTSIDE ON A SUNNY DAY

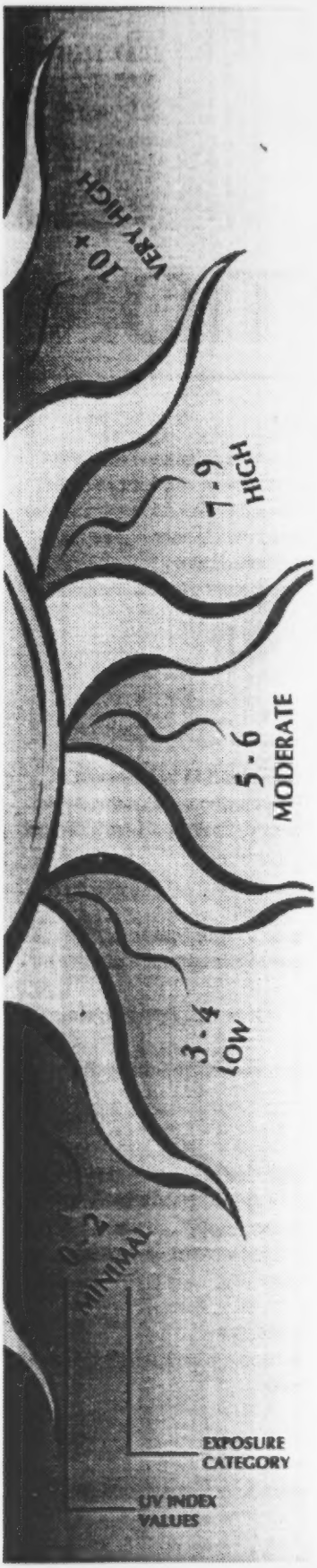
A sunscreen with a Sun Protection Factor (SPF) of at least 15 blocks most harmful UV radiation. Apply sunscreen liberally and reapply every two hours when working, playing, or exercising outdoors. Even waterproof sunscreen can come off when you towel off sweat or water.

AVOID THE MIDDAY SUN AS MUCH AS POSSIBLE

The sun's UV rays are strongest between 10 a.m. and 4 p.m. To the extent you can, limit exposure to the sun during these hours.

AVOID SUNLAMPS AND TANNING PARLORS

Sunbeds damage the skin and unprotected eyes and are best avoided entirely.



UV INDEX

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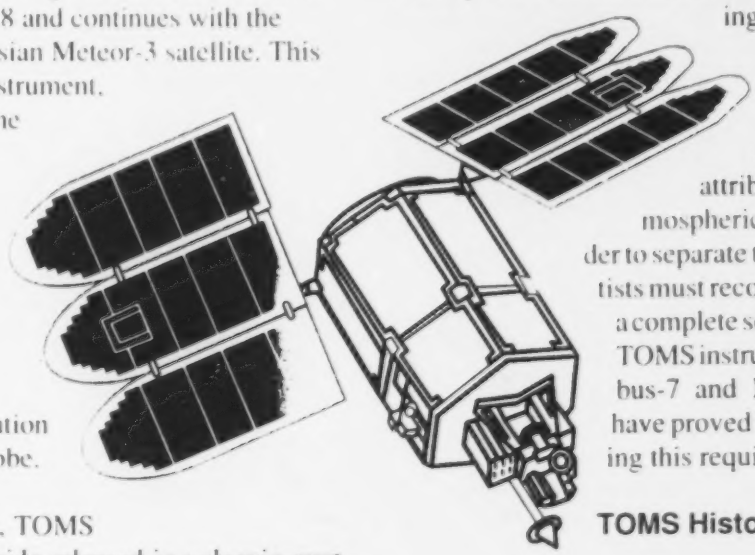
NASA Facts

National Aeronautics and
Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

NF-219

Total Ozone Mapping Spectrometer/Earth Probe (TOMS/EP-94)

The Total Ozone Mapping Spectrometer, to be launched in 1994 onboard an Earth Probe Satellite (TOMS/EP-94), will continue NASA's long term daily mapping of the global distribution of the Earth's atmospheric ozone. TOMS/EP-94 will extend the high-resolution measurement of ozone from space that began with NASA's Nimbus-7 satellite in 1978 and continues with the TOMS aboard a Russian Meteor-3 satellite. This NASA-developed instrument, which measures ozone indirectly by monitoring ultraviolet light, has mapped in detail the Antarctic "ozone hole," which forms September through November of each year, and the distribution of ozone over the globe.



In addition to ozone, TOMS measures sulfur-dioxide released in volcanic eruptions. The U.S. Federal Aviation Administration (FAA) is studying ways to use these measurements to detect volcanic ash clouds that are hazardous to commercial aviation.

Ozone, a molecule made up of three oxygen atoms, shields life on Earth from the harmful effects of the ultraviolet radiation of the Sun. The increased amounts of ultraviolet radiation that would reach the Earth's surface because of ozone depletion could increase the incidence of skin cancer and cataracts in humans, harm crops and interfere with marine life.

Researchers face two crucial problems in ozone studies. First, finding a slow, long-term trend among a variety of short-term trends, and second, ascertaining how much of the change in global ozone is due to human activities and how much is attributable to natural atmospheric processes. In order to separate these factors, scientists must record data over at least a complete solar cycle, 11 years. TOMS instruments aboard Nimbus-7 and Meteor-3 satellites have proved invaluable in meeting this requirement.

TOMS History

Prior to the development of TOMS and its predecessor, the Nimbus-4 Backscatter Ultraviolet (BUV) instrument, ozone measurements were obtained via ground-based Dobson Spectrophotometer stations. These data, while reliable, are limited because the stations only measure ozone in the atmosphere directly above them. Since its development, the NASA TOMS program has provided daily global views of ozone. TOMS is the primary source of high-resolu-

tion global maps of the total ozone content of the atmosphere. TOMS/Nimbus-7 the first TOMS instrument, provided reliable, high-resolution maps of global ozone amounts on a daily basis from October 1978 to May 1993.

During its lifetime on Nimbus-7, TOMS helped make "ozone" a household word through false-color images of the Antarctic Ozone Hole. Even after 14 years of operations, TOMS was testing new concepts such as "now-casting" of winds at flight altitudes and volcanic ash clouds. Now-casting is real-time ozone mapping that occurs when satellite data is processed and displayed on a computer screen simultaneously as the satellite passes overhead. In April 1993, during an early morning pass of NASA's Nimbus-7, scientists were able to take real-time ozone readings from TOMS.

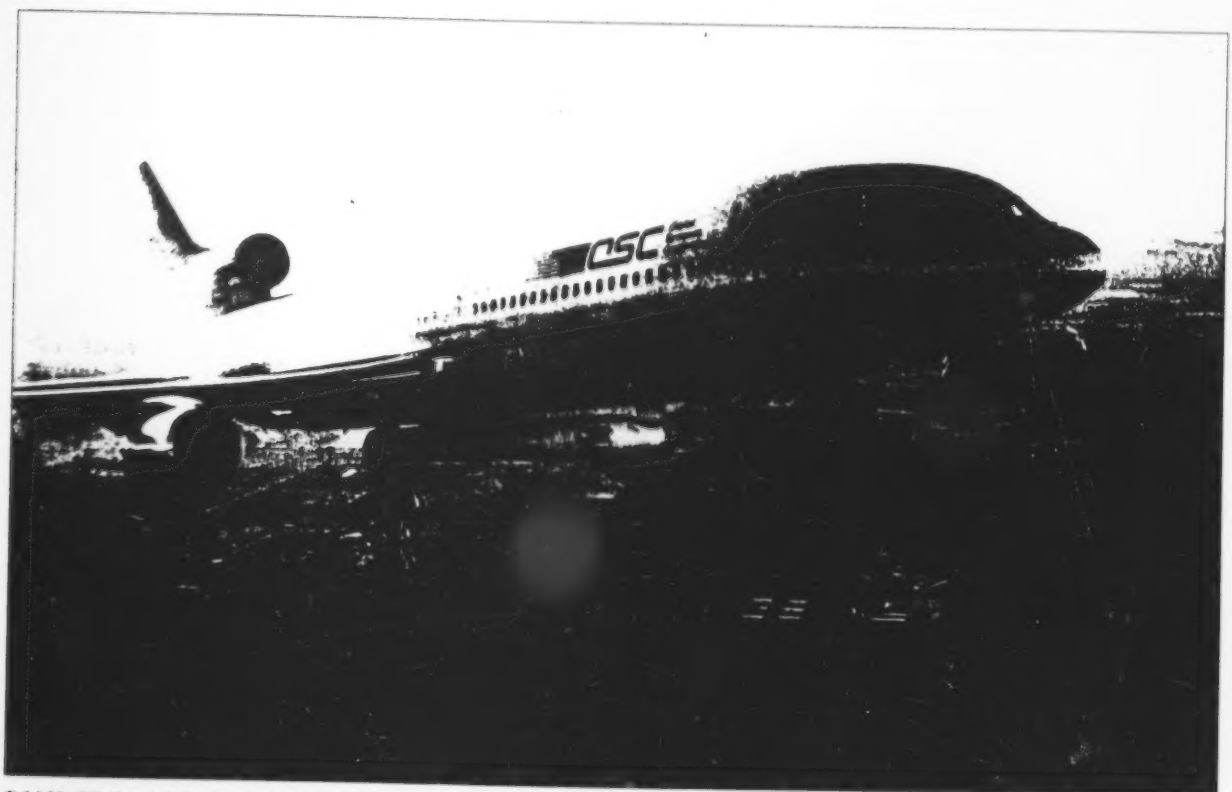
The Meteor-3/TOMS, the first significant U.S. science instrument to fly on a Russian spacecraft, is one of the main sources of ozone data until the launch of TOMS/EP-94. Meteor-3/TOMS was launched in August 15, 1991 from Plesetsk in what was then the Soviet Union.

The Launch

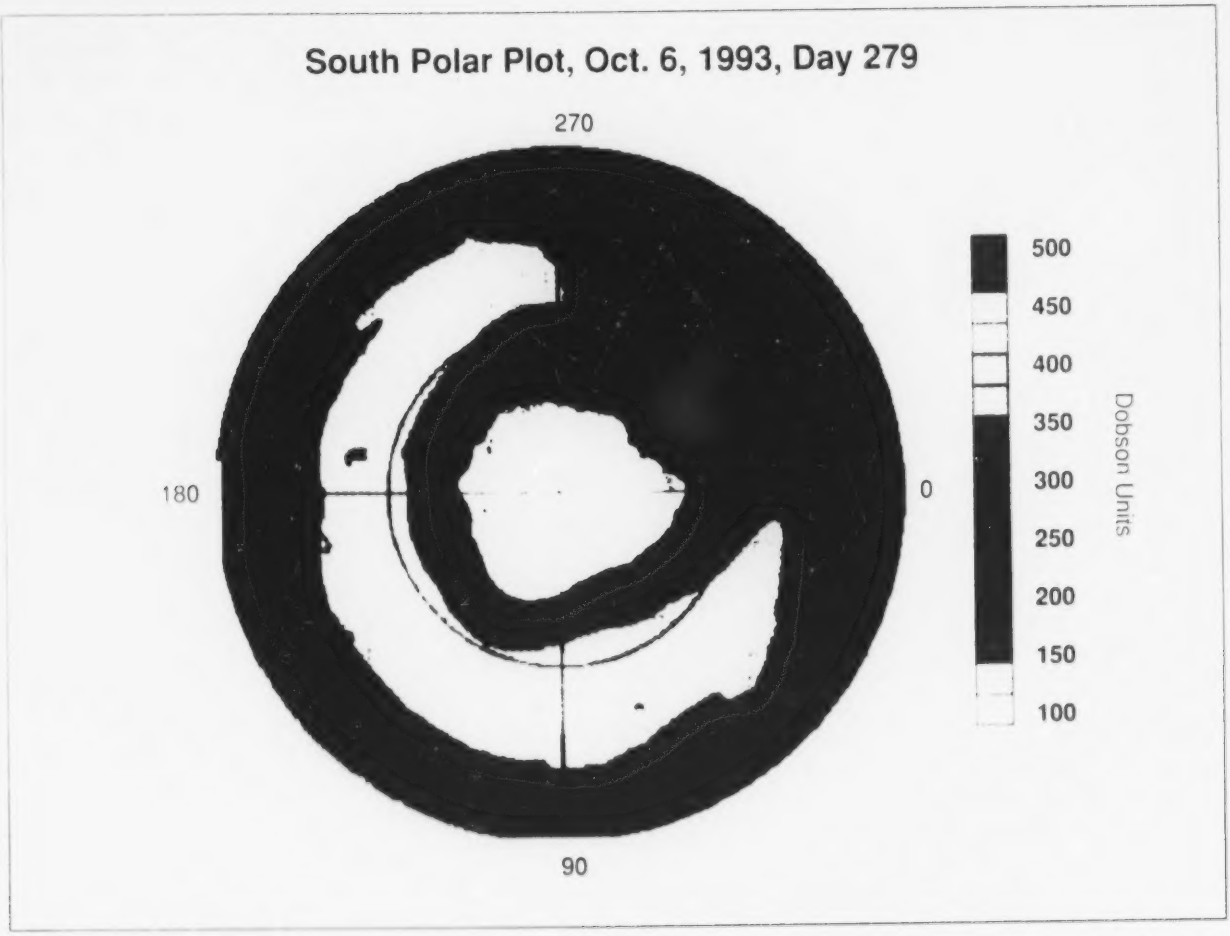
The launch vehicle for TOMS/EP-94 will be an expendable Pegasus-XL rocket, released at an altitude of 38,000 feet (11.6 kilometers) from an L-1011 jet. Following separation, an onboard hydrazine propulsion system will then raise the spacecraft to its final 600-mile (955-kilometer) circular, sun-synchronous orbit. The final orbit will be reached approximately 21 days after launch. Data collection will begin at launch plus 30 days. TOMS/EP-94, built for NASA by TRW Space & Electronics Group, Redondo Beach, Calif., has a minimum operating requirement of 2 years.

The Instrument and Measuring Techniques

The TOMS instrument is a second-generation backscatter ultraviolet ozone sounder. TOMS can measure "total column ozone"—the total amount of



TOMS/EP-94 will be sent aloft on a Pegasus rocket similar to the one shown here on the belly of an L-1011 jet aircraft. The L-1011 will drop the Pegasus 38,000 feet above Vandenberg Air Force Base, and the rocket will carry its payload into orbit.



This gray-scale image shows the total ozone in the southern hemisphere for Oct. 6, 1993. Preliminary total ozone values on this day were less than 100 Dobson units, a new record low in a region near the South Pole. The total ozone values were measured by the Total Ozone Mapping Spectrometer (TOMS) instrument aboard the Russian Meteor-3 satellite, launched in August 1991. The gray-scale at the right side of the figure shows the total ozone values. The Antarctic ozone hole is located in the center of the figure and is indicated by the black and white colors. Prior to 1975, values of total ozone between 250 and 300 Dobson units (dark to medium gray) were normal, indicating a decrease of about 150 Dobson units.

ozone in a "column" of air from the Earth's surface to the top of the atmosphere—under all daytime observing and geophysical conditions. It consists of an instrument, capable of measuring "total columnar ozone" under all daytime observing and geophysical conditions. TOMS observations cover the near ultraviolet region of the electromagnetic spectrum, where sunlight is absorbed only partially by ozone.

TOMS/EP-94 measures total ozone by observing both incoming solar energy and backscattered ultraviolet (UV) radiation at six wavelengths. "Backscattered" radiation is solar radiation that has penetrated to the Earth's lower atmosphere. There, it is scattered by air molecules and clouds back through the stratosphere to the satellite sensors. Along that path, a fraction of the UV is absorbed by ozone. By comparing the amount of backscattered radiation to observations of incoming solar energy at identical wavelengths, scientists can calculate the Earth's albedo, the ratio of light reflected by Earth compared to that it receives. Changes in albedo at the selected wavelengths can be used to derive the amount of ozone above the surface.

TOMS makes 35 measurements every 8 seconds, each covering 30 to 125 miles (50 to 200 kilometers) wide on the ground, strung along a line perpendicular to the motion of the satellite. Almost 200,000 daily measurements cover every single spot on the Earth

except areas near one of the poles, where the Sun remains close to or below the horizon during the entire 24-hour period.

In addition to various "housekeeping" sensors to monitor the well-being of the instrument, TOMS uses several in-flight calibration modes to assess system performance. In addition, data from instruments carried on the Space Shuttle as part of the Atmospheric Laboratory for Applications and Science (ATLAS) program provide calibrations to help refine TOMS data.

The Future

The extremely high quality of TOMS ozone data has also helped scientists in detecting a small but steady long-term damage to the ozone layer over several parts of the globe, including some of the heavily populated areas in the northern mid-latitudes. This discovery led to the curtailment of the production of ozone-depleting chemicals through an international treaty signed in Montreal in the 1980s. To ensure that ozone data will be available throughout the next decade, NASA will continue the TOMS program using U.S. and foreign launches. The Japanese Advanced Earth Observations Satellite (ADEOS) will carry a fourth TOMS into orbit when it launches in 1996, and a fifth TOMS Instrument is being assembled for flight in 1998 on an undetermined satellite. The TOMS program is managed by NASA's Goddard Space Flight Center, Greenbelt, Md., for the Office of Mission to Planet Earth, Washington, D.C.

TOMS is part is NASA's Mission to Planet Earth, a long term, coordinated research effort to study the Earth as a global environmental system. Using the unique perspective available from space, NASA will observe, monitor and assess large-scale environmental processes, focusing on climate change. MTPE satellite data, complemented by aircraft and ground data, will allow humans to better understand natural environmental changes and to distinguish natural changes from human induced changes. MTPE data, which NASA will distribute to researchers worldwide, is essential to humans making informed decisions about their environment.

May 1994

Especially for kids and their families

The Mini Page®

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By BETTY DEBNAM

from The Mini Page by Betty Debnam © 1994 Universal Press Syndicate

Working to Solve . . .

The Ozone Problem

What's up? We often ask this question when we want to find out what is happening.

This Mini Page issue is about scientists whose job it is to find out what is up in the air.

Scientists often go to isolated Antarctica to research the effects of chemicals and pollutants up in the air.

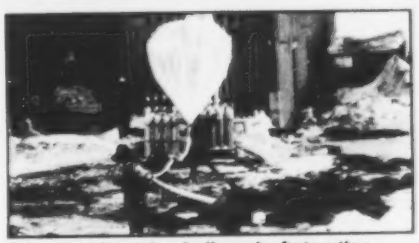


photo courtesy of the State Historical Society of Wisconsin

Scientists launch a balloon in Antarctica. They use balloons to carry instruments up in the air to measure the ozone.

Bad ozone

Ozone is a gas. Ozone is the same substance everywhere. It can be bad or good depending on where it is.

The bad ozone is closer to Earth, mostly in or near our cities where there is a lot of pollution.

When sunshine hits a special mix of pollutants, a chemical reaction occurs. This ozone mixture is known as smog.

The area around the North Pole is called the Arctic.

The area around the South Pole is called Antarctica.

Good ozone

The good ozone exists naturally and forms a shield way up in our atmosphere, about seven or more miles up. This shield protects us from the sun's rays. It helps to keep us from getting skin cancer.

Sometimes chemicals travel up into the atmosphere and destroy the good ozone. When this happens, more of the sun's rays get through to Earth. Over Antarctica the ozone layer is thinner than over the rest of the Earth. We call this the "ozone hole."

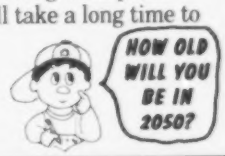
Studying the air

Dr. Susan Solomon is an atmospheric chemist. She studies chemicals in the air. Her special interest is the ozone layer.

She led the first national ozone expedition to Antarctica in the fall of 1986. She researched the ozone hole.

Dr. Solomon says: "The ozone layer has been depleted over Antarctica by human activities. We only have about half as much ozone in the Antarctic spring now as we did 15 years ago."

People have begun working to stop the damage. However, it will take a long time to fix. Dr. Solomon expects the ozone problem to be with us until around 2050.



The Mini Page thanks Dr. Susan Solomon of the National Oceanic and Atmospheric Administration.

This Mini Page is based on a permanent exhibition, "Science in American Life," at the National Museum of American History, Smithsonian Institution, Washington, D.C. The exhibition is made possible by a grant from the American Chemical Society.

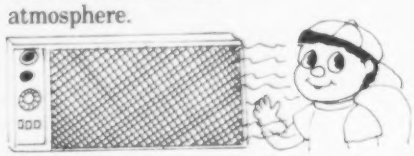
CFCs

We get many benefits from using chemicals such as chlorofluorocarbons, or CFCs for short.

For many years, CFCs were used to spray paints and hairsprays out of cans.

They were also used in air conditioners and refrigerators. These miracle chemicals kept us cool and our food fresh and safe.

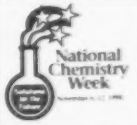
However, scientists began to realize there were hazards when we released tons of CFCs into the atmosphere.



Working together

After scientists discovered that we were losing some of our ozone shield, the U.S.A. and 70 other countries agreed to limit the use of CFCs.

This agreement marked one of the first times ever that so many countries joined together to fight an environmental problem.



The week of Nov. 6-12 is National Chemistry Week. Chemistry is part of our everyday life. One purpose of this week is to encourage kids to learn more about chemistry.

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A Report From Antarctica

The Mini Page asked Dr. Solomon to tell us what doing research in Antarctica was like. Here are some of the interesting things we learned from her:

Her job

"I like atmospheric chemistry because it is taking place in the whole world, not just in a test tube.

"What I like most about being a scientist is that you learn new and interesting things every day of your life."

photo courtesy Dr. Susan Solomon

Dr. Solomon poses on a hill overlooking McMurdo Station. No people live there permanently. It's like a little town overlooking a harbor. There is a church, hospital, bowling alley, and a community center where videos and movies are shown.

photo courtesy Dr. Susan Solomon

Dr. Susan Solomon stands in a dry valley in Antarctica, where there is very little snow. She says, "If you're going any distance from the station, you go in a helicopter."

What do you feel?

"If I had to use one single word to sum up Antarctica, it would be 'cold.' The typical springtime temperature can be -30 to -40 degrees. With the wind chill, it can get colder than that. Minus -100 is not unusual."

What do you hear?

"It is very quiet. There are no airplanes overhead, no traffic. There are lots of times that the only things you hear are your own heartbeat and the wind rushing in your ears."

What do you see?

"Endless white emptiness. When you fly into Antarctica, there are no telephone poles, no power lines. You fly for thousands of miles with nothing but emptiness beneath you ... just open, white emptiness beneath you.

"It is very, very white and very, very blue. In the winter it is dark 24 hours a day. In the summer it is light 24 hours a day.

"The springtime is a beautiful time because you get very long sunrises and sunsets."

photo by R. Sanders

Dr. Solomon and other scientists arrive in Antarctica in the winter — at noon, Aug. 23, 1986. In the winter it's dark 24 hours a day. Solomon says, "That's as bright as it's going to get."

What do you smell?

"Nothing, because everything is frozen. One of the things that is striking when you come back from Antarctica, when you approach New Zealand, you suddenly realize that you are smelling plants and vegetation. It is very striking that you are smelling living things again after not smelling anything."

At work in Antarctica

Food

For enough energy to keep warm, people need to eat more than twice as much as they usually do. People store food in refrigerators to keep it from freezing!

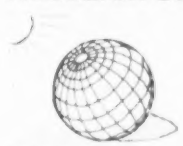
Clothing

People need to wear special parkas, insulated rubber boots, long underwear, hats and gloves, as well as regular clothing.

Seasons

If it's summer here, it's winter there. Our seasons are opposite from Antarctica's.

Research stations



No country owns Antarctica. It is governed by a treaty that says it can be used for peaceful purposes only. Several countries have research stations there.

To do: Pretend that you are going on an expedition to Antarctica. Make a list of some of the things you would like to carry with you. Make another list of what you would like to find out.

Next week, The Mini Page celebrates the 75th anniversary of Children's Book Week.

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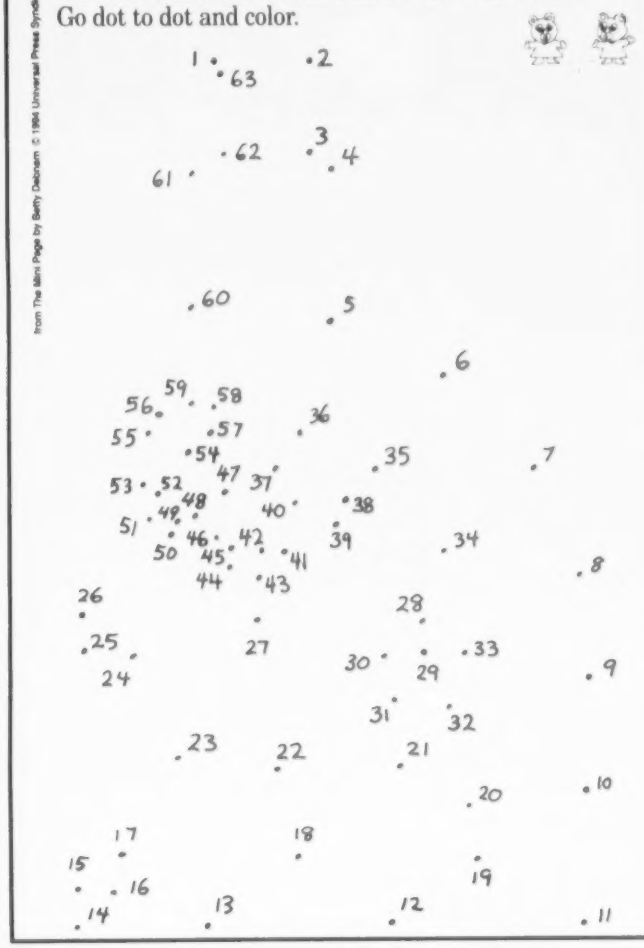
The Mini Page Book of States is packed with helpful information on every state: capitals, birds, flowers, trees, industry and crops, geographical and historical facts, and more. To order, send check or money order for $4.95 plus $1 postage and handling per copy, payable to Andrews and McMeel, P.O. Box 419242, Kansas City, Mo. 64141.

This is an instrument scientists and chemists use. Go dot to dot and color.



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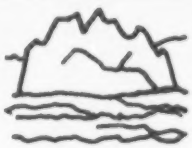
Antarctica: a frozen lab

Weather

- Average temperature at McMurdo Station: -9 degrees F
- Highest: 59 degrees F
- Lowest: -126 degrees F
- Strongest winds: 200 mph. It is the windiest place on Earth.

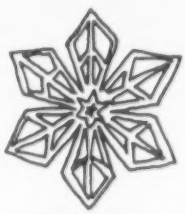
photo courtesy National Science Foundation

A huge iceberg frozen in McMurdo Sound.



Size

- It's the fifth-largest continent, with 5.4 million square miles. (The U.S. covers 3.6 million square miles.)



Water

- Antarctica has 70 percent of the world's fresh water, which is in the form of ice.
- It is known as the world's largest desert because it gets fewer than 2 inches of moisture per year.

Ice

- Ice up to 3 miles thick covers 97.6 percent of the surface. The rest is rocks.

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Especially for kids and their families

The Mini Page

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Teacher's Guide

For use by teachers and parents at home and at school.
For use with issue: The Ozone Problem

Main idea: This issue is about the ozone layer. The following is a list of activities to be used with this issue. They are listed in order of difficulty. Ask the children to do the following:

1. Make a list and draw a picture of things that are up in the air.
2. Study the weather page in your paper. What is the coldest city? Compare that temperature with the average temperatures in Antarctica.
3. The seasons in Antarctica are opposite from ours. Make a chart showing this.
4. Do some research to find out more about this frozen continent. Then hold a press conference. Assign some students to be reporters and others to be scientists just back from Antarctica.
5. Look through your newspaper and see if there are any stories about the environment.
6. Study the content labels of five different products that we use every day, such as toothpaste, hairspray or shampoo. Make a list of the chemicals in each one. Compare the lists. Are any chemicals used for more than one product? Are there any warnings on the labels?
7. Make a list of other environmental problems facing our planet Earth.

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MIGHTY FUNNY'S Mini Jokes

(sent in by Breeann Briggs)

Q: What kind of tick goes crazy around you?
A: A lunatic!

(sent in by Diane Nemr)

Q: What does a 500-pound mouse say?
A: "Here, kitty, kitty."

(sent in by Lee Lindsey)

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PETER PENGUIN'S PUZZLE LE-DO

Look at the pictures to figure out what people wear in Antarctica. Fill in the blocks below.

ACROSS:

3.

5.

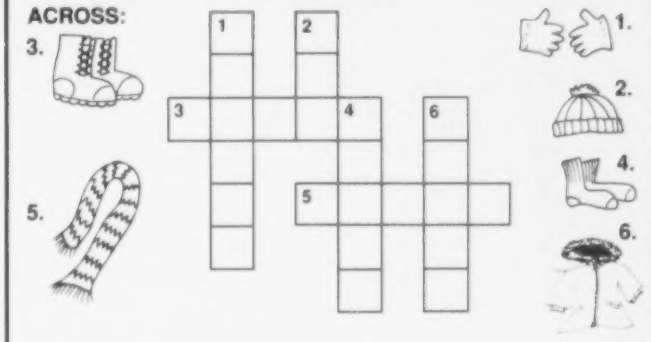
DOWN:

1.

2.

4.

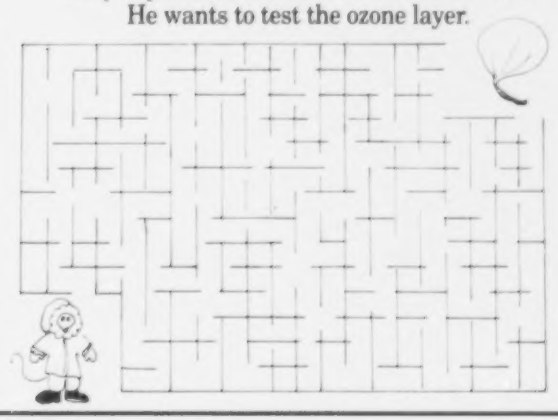
6.



Answers: Down: 1. gloves, 2. hat, 4. socks, 6. parka; Across: 3. boots, 5. scarf.

MAZE

Help Alpha Mouse find the weather balloon. He wants to test the ozone layer.



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Rookie Cookie's Recipe

Good Morning Muffin

You'll need:

- 1 teaspoon butter or margarine, melted
- 1 egg
- 1 English muffin, split in half and toasted
- 1 slice of your favorite cheese

What to do:

1. Place melted butter or margarine in a microwave-safe measuring cup.
2. Crack egg open and pour into measuring cup with melted butter or margarine. Stir until well-mixed.
3. Microwave on HIGH 45 seconds.
4. Place 1/2 of English muffin on a microwave-safe plate.
5. Place cooked egg on top of English muffin.
6. Place cheese slice on top of egg.
7. Microwave on HIGH 15-20 seconds or until cheese starts to melt.
8. Place other half of English muffin on top.

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Meet Jodie Sweetin

Jodie Sweetin, 12, plays Stephanie, the middle daughter on the show "Full House."

Jodie was born in Los Angeles.

When she grows up, she would like to be a dancer, a teacher, an astronaut and an actress.

She has been in several commercials and had a part in the show "Valerie."

Jodie's hobbies include dancing, swimming, riding her bike, reading and playing video games.

She is a good student and loves school.

She lives in Cypress, Calif., with her parents and dog, Lacey.

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Mini Spy . . .

Mini Spy and Alpha Mouse are doing an ozone test in Antarctica. See if you can find:

- lips
- word MINI
- tooth
- snake
- comb
- caterpillar
- mug
- dolphin
- letter U
- fish
- letter Z
- number 3
- ladder
- heart
- cat

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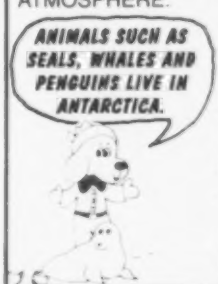
BASSET BROWN THE NEWS HOUND'S OZONE TRY 'N FIND

Words that remind us of the ozone layer are hidden in the block below. Some words are hidden backward or diagonally. See if you can find: OZONE, GAS, OXYGEN, ATOMS, MOLECULES, ULTRAVIOLET, LAYER, EARTH, CHEMICALS, SCIENTISTS, PROTECT, ENVIRONMENT, SPRAY, MEASURE, CFC, ATMOSPHERE.



O E A H S C I E N T I S T S O
B X A E R U S A E M I C F C Z
C J Y R P V T E C T O R P A O
D K Q G T M O L E C U L E S N
E G A S E H R W A T O M S L E
R E Y A L N S L A C I M E H C
S P R A Y E R E H P S O M T A
F T N E M N O R I V N E M S Y
U L T R A V I O L E T G N T Z

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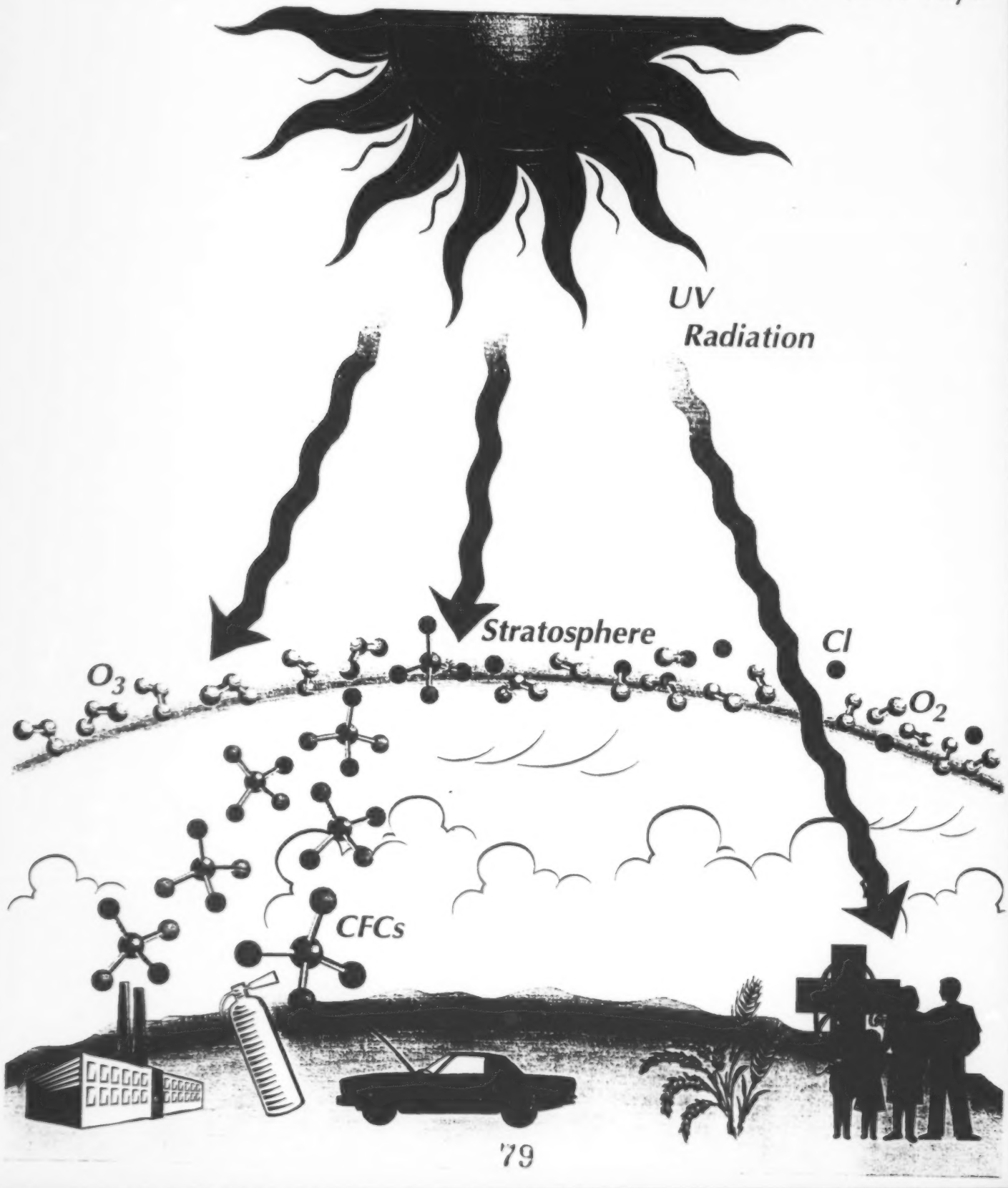
Ozone-depleting chemicals such as CFCs damage the stratospheric ozone layer, which shields the Earth from dangerous ultraviolet (UV) rays.



GRAPHIC ON REVERSE SIDE INTENDED FOR USE AS AN OVERHEAD

OZONE DEPLETION

The ozone layer forms a thin shield in the stratosphere, protecting life on Earth from the sun's harmful ultraviolet (UV) rays. In the 1980s, scientists began accumulating evidence that the ozone layer was being depleted. Depletion of the ozone layer can result in increased UV radiation reaching the Earth's surface, which can lead to greater chance of overexposure to UV rays and the consequent health effects, including skin cancer, cataracts, and immune suppression. Increased UV radiation also endangers the environment by reducing important crop yields and threatening animal and plant life.

HOW STRATOSPHERIC OZONE PROTECTS US

Ozone is a naturally occurring gas found in the Earth's atmosphere that absorbs certain wavelengths of the sun's UV radiation. Ozone is concentrated in a part of the atmosphere called the stratosphere. Stratospheric ozone is most concentrated between 6-30 miles above the Earth's surface.

Ozone is formed when oxygen molecules absorb UV radiation and split apart into two oxygen atoms (O), which combine with other oxygen molecules (O_2), to form ozone molecules (O_3). Ozone is also broken apart as it absorbs UV radiation. In this way, UV helps sustain the natural balance of ozone in the stratosphere, while ozone in turn absorbs UV, protecting life on Earth from harmful radiation.

OZONE DEPLETION

Chlorofluorocarbons (CFCs) are used widely in industry and elsewhere as refrigerants, insulating foams, and solvents. They migrate into the upper atmosphere after use. Because they are heavier than air, they have to be carried by air currents into the stratosphere, a process that can take as long as 5 to 10 years. These chemicals absorb UV radiation, break apart, and react with ozone, taking one oxygen atom away and forming highly reactive chlorine monoxide. Chlorine monoxide (ClO) in turn breaks down O_3 again by pulling away a single oxygen atom, creating two O_2 molecules, and allowing the Cl to move freely to another ozone molecule. In this way each chlorine atom acts as a catalyst, repeatedly combining with and breaking apart as many as 100,000 ozone molecules during its stratospheric life.

Other compounds also damage the ozone layer in much the same way as do CFCs. These ozone-depleting substances include pesticides such as methyl bromide, halons used in fire extinguishers, and methyl chloroform used in industrial processes.

WHAT IS BEING DONE ABOUT OZONE DEPLETION

Countries around the world have recognized the threats posed by ozone depletion and have responded by adopting the Montreal Protocol on Substances That Deplete the Ozone Layer. Parties to this treaty, including the United States, are phasing out the production of ozone-depleting substances.

EFFECT OF OZONE LAYER DEPLETION ON UV RADIATION LEVELS

Scientists predict that CFC levels should peak by the turn of the century and should fall to 1979 levels between the years 2020 and 2050. As international control measures reduce the release of CFC's and other ozone-depleting substances, the natural atmospheric process will repair the ozone layer. Until that time, we can expect increased levels of UV at the Earth's surface. These increased UV radiation levels can lead to a greater chance of overexposure to UV rays resulting in threats to our health and the environment.

Ozone Layer Educator Resources

CD ROM

EPA/NOAA, *Global Ecosystems Database*
National Geophysical Data Center
325 Broadway
Boulder, CO 80303
tel: 303-497-6125
Fax: 303-497-6513

Workshops for teachers to work with scientific data on disks. Also *Global Change Data Base for Africa* with workbook exercises for classrooms and self-instruction - college. Audience: scientists.

NASA-Goddard, NSSDC, *Ozone*, TOMS gridded data, NSSDC Coordinated request and use support office. Gridded ozone data, color images in daily and monthly averages for 1978-91 and daily zonal mean ozone updates. Audience: scientists.

Dr. Richard McPeters
NASA-Goddard
Greenbelt, Maryland 20771
301-286-3832

U.S. Geological Survey, Department of Interior *JEDI:* Ozone, Sea Level. Joint Educational Initiative, databases from NASA, NOAA, USGS, 2 gigabytes of world wide data and information, $35. Audience: middle and high schools.

Jim Sproull
JEDI Teacher Coordinator
USGS
Reston, VA 22092
703-648-6636
FAX 703-648-6683

COMPUTER DISCS

National Geophysical Data Center, NOAA, *Global Change*. 18 diskettes with documentation and teacher's guide. Audience: middle school.

NOAA, E/GCI, Department 891
325 Broadway
Boulder, CO 80303
303-497-6125
FAX 303-497-6513

Save the Planet Software.
Current ozone research, graphics, images, maps, formulas, 1991 Antarctic ozone hole, health and environmental risks. $24.95 Audience: Students and general.

Save the Planet Software Serving the Environmental Community
P.O. Box 45
Pitkin, CO 81241
303-641-5035

PRINT MATERIAL

Bureau of Meteorology
Ozone monograph, color graphics

Ozone Science Unit
Bureau of Meteorology
GPO Box 1289K
Melbourne, Victoria
Australia 3001
669-4000

Canadian Aerosol Information Bureau, greenhouse gases and ozone depletion Monograph.
Audience: middle and high schools.

Canadian Aerosol Information Bureau
56 Sparks Street, St. 702
Ottawa, Ontario, Canada, KIP 5A9

EPA, "Stratospheric Ozone Information Hotline"
Hotline operators respond to questions and distribute materials on Title VI (Stratospheric Protection) of the Clean Air Act.

U.S. Environmental Protection Agency
Washington, DC
1-800-296-1996

NASA, Goddard Teacher Resource Center, "Fact Sheets," ozone, greenhouse, oceans.
Audience: schools, general.

Linda Matys
Teacher Resources Center, NASA
Greenbelt Road
Greenbelt, MD 20771
301-286-8570

NOAA/National Weather Service (NWS), "Weather."

Hank Robinson
Meteorology NWS
SSMCI - 13123
Silver Spring, MD 20910
301-713-1970
FAX 303-497-6513

NOAA/Office of Global Programs (OGP) ***Reports to Nation*****: "The Climate Systems," "Our Ozone Shield," "EL Nino."** Monograph series with excellent graphics exploring timely climate and global change topics. Audience: general.

Office for Interdisciplinary Earth Studies, UCAR
P.O. Box 3000
Boulder, CO 80307-3000
303-497-1682
FAX 303-497-1679

Report, United Nations Environment Programme, "Environmental Effects of Ozone Depletion: 1991 Update" and "Environmental Effects Panel Report." Panel report pursuant to Article 6 of the Montreal Protocol. Limited supply. Or call the Stratospheric Ozone Information Hotline 1-800-296-1996.

Ozone Secretariat
K.M. Sarma UNEP
P.O. Box 30552
Nairobi, Kenya, Africa
02542-521928-29-34
FAX 02542-521930

Smithsonian Institution, Air & Space Museum, "Blue Planet." Accompanies IMAX *"Blue Planet,"* background information and classroom activities on environmental and Earth science topics. Audience: grades 3-12.

Carolyn Schmidt
Office of Education
National Air & Space Museum
Smithsonian Institution, Room 211
Washington, DC 20560
202-786-2106
FAX 202-786-2262

University of Hawaii Sea Grant, "Ozone--The Hole Story." Booklet explaining ozone depletion and alternatives for action, includes cartoons and graphics. Audience: general.

Bruce Miller and Scott Bogle, UHSGES
University of Hawaii-Manoa
1000 Pope Road
Honolulu, HI 96822
808-956-8645
FAX 808-956-2858

VIDEO

Dupont, "Saving the Ozone Layer: The Search for Solutions." Industry, legislators and public to phasing out CFC's, 26-min. video, 1990, available in English, French, German, Spanish, and Italian.

Vivian Sheridan
P.O. Box 50, Grand-Saconnex
Geneva, Switzerland
41-22-717-5111
FAX 41-22-717-5109

United Kingdom, TVE Distribution Center, "Ozone Alert", animated film, CFC molecules are red creatures and gobble up ozone; 5-min. video, 1990, available in English.

Ingrid Zwartjes
TVE Distribution Center
Postbus 7, NL - 3700 AA
Zeist, Netherlands,
31-3404-204-99
FAX 31-3404-224-84

S.C. Johnson Wax, "Ozone: The HOLE Story." Aired on PBS nationwide, video with accompanying teaching unit.

S.C. Johnson Wax
1525 Howe St.
Racine, Wisconsin 53403

"Ozone: Double Trouble"
EPA in conjunction with
North Carolina State University

A 20-minute video explaining the difference between beneficial ozone in the stratosphere, and harmful ozone in the troposphere. Free copies available while supplies last. Call the Stratospheric Ozone Information Hotline (1-800-296-1996)

NASA RESOURCES

NASA SpaceLink
http://spacelink.msfc.nasa.gov

NASA Home Page
http://www.nasa.gov/

NASA's Central Operation of Resources for Educations (CORE)
was established for the national and international distribution of NASA-produced educational materials in audiovisual format. Educators can obtain a catalogue of these materials and an order form by written request on school letterhead to:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
PHONE:(216) 774-1051, ext. 293/294

Teacher Resource Center Network

To make additional information available to the education community, the NASA Education Division has created the NASA Teacher Resource Center network. TRCs contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, videotapes, telelecture programs, computer programs, lesson plans, and teacher guides with activities. Contact the TRC in your region for details on its services.

AK, AZ, CA, HI, ID, MT, NV, OR, UT, WA, WY
NASA Teacher Resource Center
Mail Stop T12-A
NASA Ames Research Center
Moffet Field, CA 94035-1000
(415) 604-3574

CT,DE,DC, ME, MI, MA, NH, NJ, NY PA, RI, VT,
NASA Teacher Resource Laboratory
Mail Code 1303
NASA Goddard Space Flight Center
Greenbelt, MD 20771-0001
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How to Access NASA Education Materials and Services, PED-329 April 1995. This brochure serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the TRC network.

Ozone Depletion is a Fact!

After more than twenty years of research, there is no doubt that the ozone layer is thinner than it used to be. A veil of gas that screens the Earth from powerful solar radiation, the ozone layer has been gradually eroded over populated areas worldwide, as well as over Antarctica. Higher levels of ultraviolet (UV-B) radiation at the Earth's surface have been recorded and could pose serious human health and ecological risks. Scientists around the world agree that increased UV-B radiation will lead to more cases of skin cancer and cataracts. Also, damage may occur to important crops, livestock, and marine ecosystems.

Chlorine from chemical refrigerants called chlorofluorocarbons (CFCs) is a major cause of ozone depletion. Although heavier than air, CFCs are transported by wind currents 10–30 miles up to the stratospheric ozone layer. Ultraviolet rays then break down the CFCs, freeing the chlorine atoms to destroy ozone. Remaining active for more than 100 years, chlorine from CFCs emitted today will continue to deplete ozone well into the next century. Fortunately, chlorine from other sources such as seawater, swimming pools, and volcanoes falls out with the rain before reaching the ozone in the upper atmosphere.

CFCs, however, do not act alone in this cycle of ozone depletion. HCFC refrigerants (hydrochlorofluorocarbons) also add chlorine to the stratosphere, but in smaller quantities than CFCs. Another chlorine-based ozone depleter is methyl chloroform, a cleaning solvent. Other compounds destroy ozone because they contain bromine. The most common ozone depleters with bromine are halons, used in fighting fires, and the agricultural pesticide methyl bromide.

The New Clean Air Act

The Clean Air Act of 1990 contains many measures to protect the ozone layer. Most important, the law requires a gradual end to the production of chemicals that deplete the ozone layer. CFC refrigerants found in car air conditioners, household refrigerators, and dehumidifiers—also known as R-12—will no longer be produced after 1995. HCFC refrigerants for window and central air-conditioning units—also known as R-22—will be produced until 2020. The production of halons ended after 1993, while methyl bromide production will be limited beginning in 1994 and phased out by 2001.

The Clean Air Act also bans the release of ozone-depleting refrigerants during the service, maintenance, and disposal of air conditioners and all other equipment that contains these refrigerants. Individuals who work on such equipment must follow EPA regulations for ozone-safe service practices, including the recovery and recycling of refrigerant. Vigorous refrigerant conservation will reduce emissions of these harmful chemicals and help assure a continued supply to service existing equipment.

The national program to protect the ozone layer also involves approving substitute chemicals, banning nonessential uses of ozone-depleting compounds, and labeling products containing or manufactured with ozone-depleting substances.

Protect Your Health

Common sense is the best defense. Some simple precautions can substantially reduce your risk of skin cancer and cataracts. Avoid over-exposure to the sun at mid-day when UV-B rays are the strongest. Wear sunscreen, sunglasses, hats, and other protective items.

To learn more about ozone depletion, call EPA's Stratospheric Ozone Information Hotline at 800-296-1996, 10:00 a.m. to 4:00 p.m. (Eastern), Monday through Friday.

United States Environmental Protection Agency

EPA 430-F-94-007
April 1994

Office of Air and Radiation (6205 J)

EPA

Protecting the Ozone Layer

A Checklist for Citizen Action

Before you turn on the air conditioner in your home and car this year, stop and think about the last time they were serviced. Leaky systems and careless service practices can lead to the release of refrigerant known to destroy the ozone layer. Proper maintenance and seasonal checkups of air conditioners and other appliances with refrigerant will help reduce this problem.

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What you can do to protect the ozone layer

✔ Car Air Conditioners

Have your car air-conditioning system properly serviced. Only certified technicians using approved recovery or recycling equipment may work on car air conditioners. Ask your service center if its technicians and equipment meet EPA requirements before agreeing to service.

Check for leaks. Fixing leaks in car air conditioners before more refrigerant is added helps prevent unnecessary loss of CFC refrigerants and conserves supplies. While federal law does not require leak repair, your state might.

Ask about retrofitting. Most car air conditioners sold prior to 1994 were designed to use CFCs, but can be modified to use a nonozone-depleting refrigerant. The decision to switch is up to you. A good time to retrofit might be when you make other major repairs to the air conditioner.

✔ Old Appliances

Dispose of old appliances containing refrigerant responsibly. CFC- and HCFC-refrigerant must be removed from an appliance before it is discarded. Ask the public works department in your town or a home appliance dealer about appliance recycling and refrigerant-recovery programs.

Help start a refrigerant recovery and recycling program in your area. Contact EPA's Stratospheric Ozone Information Hotline at 800-296-1996 to learn about innovative steps some communities have taken.

✔ Home Air Conditioners and Other Appliances

Ensure that refrigerant is recovered from air conditioners, refrigerators, and dehumidifiers. Refrigerant must not be "vented" during the servicing of home appliances. Used refrigerant can be recycled. Before agreeing to service, ask if the technician will use refrigerant-recovery equipment if the refrigerant needs to be removed. Also, ask if the technician is or plans to be certified by an EPA-approved testing organization.

Repair leaks. Ask the service technician to locate and repair leaks before refilling (or "recharging") your system with refrigerant. While not required by law, this will save you money in the long run and prevent unnecessary refrigerant emissions.

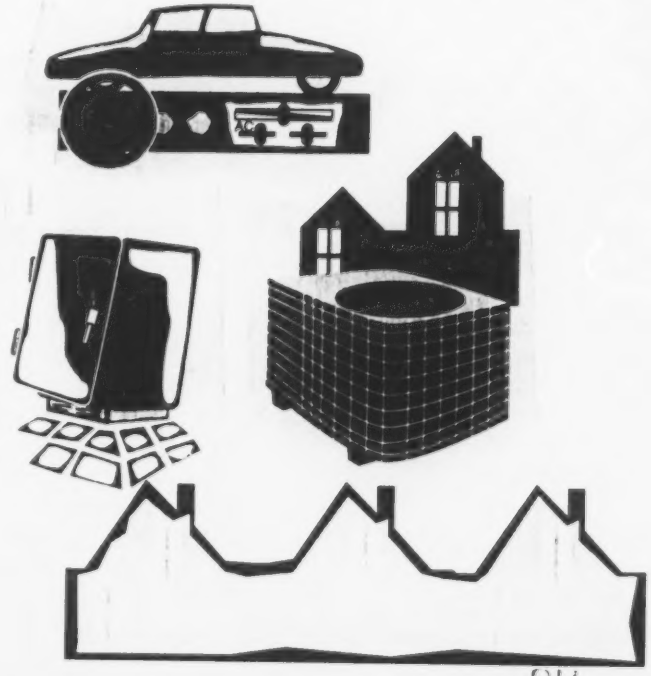
✔ Violation Reports

Call the Hotline. If you suspect or witness unlawful releases of refrigerant or other improper service practices, you can file a report easily and anonymously by calling the Stratospheric Ozone Information Hotline at 800-296-1996.

✔ Other Actions

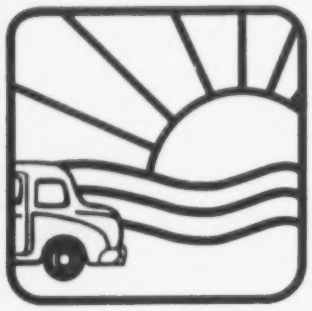
Become active in your community. Speak with your neighbors and friends about how their appliances with refrigerant can contribute to ozone depletion.

Be an informed consumer. Look for labels identifying products manufactured with or containing ozone-depleting substances. Consider alternatives, where available, that do not damage the ozone layer.



range is $100 to over $800), the decision to retrofit may make more sense for some vehicles than others. For vehicles under warranty, please consult your dealer.

Follow recommended procedures. Vehicle manufacturers are working diligently to identify the retrofit procedures for each of their models that would permit the use of HFC-134a while maintaining reliability and cooling performance. If you choose to retrofit, make sure that your service center uses the manufacturer's recommended alternative refrigerant and follows its recommended procedures. For a list of available procedures, call the Stratospheric Ozone Information Hotline at (800) 296-1996. Also, be sure the retrofit includes a label and new HFC-134a fittings.



Buying a vehicle? Ask if the air conditioner uses HFC-134a, and if not, find out about any applicable warranties covering air conditioning service and repair. If you buy an extended warranty or service contract, make sure you find out whether it covers future air conditioning repairs or services.

EPA and the automotive industry are working together to make the transition away from ozone-depleting chemicals as smooth as possible, but we need your support and cooperation to make this effort a success.

This pamphlet was developed by EPA in cooperation with:

Federal Trade Commission (FTC)

American Automobile Manufacturers Association (AAMA) members: Chrysler Corporation; Ford Motor Company; General Motors Corporation.

Association of International Automobile Manufacturers (AIAM) members: American Honda Motor Company, Inc.; American Isuzu Motors, Inc.; American Suzuki Motor Corporation; BMW of North America, Inc.; Fiat Auto U.S.A., Inc.; Hyundai Motor America; Kia Motors America, Inc.; Land Rover North America, Inc.; Lotus Cars U.S.A.; Mazda Motors of America, Inc.; Mitsubishi Motor Sales of America, Inc.; Nissan North America, Inc.; Porsche Cars North America, Inc.; Rolls-Royce Motor Cars, Inc.; Rover Group USA, Inc.; Subaru of America, Inc.; Toyota Motor Sales U.S.A., Inc.; Volkswagen of America, Inc.; Volvo North America Corporation.

Office of New York State Attorney General G. Oliver Koppell
Mobile Air Conditioning Society (MACS)
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Alliance for Responsible Atmospheric Policy
National Automobile Dealers Association (NADA)
National Institute of Automotive Excellence (ASE)
International Mobile Air Conditioning Association (IMACA)
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For further information, please call the Stratospheric Ozone Information Hotline 1-800-296-1996. Hours: 10:00 am - 4:00 p.m., Monday through Friday, except federal holidays.

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United States Environmental Protection Agency
EPA430-F-94-009
May 1994

Office of Air and Radiation (6205J)

EPA

Auto Air Conditioners and the Ozone Layer: A Consumer Guide

This pamphlet was developed to help you - the owner or prospective owner of an air conditioned car or truck - understand how efforts to protect the ozone layer will affect you and your vehicle now and in the future.

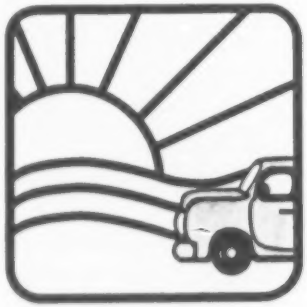
1. Our Threatened Ozone Layer

Scientists worldwide have concluded that chlorofluorocarbons (CFCs, also known by the trade name Freon) deplete the ozone layer. CFCs have been used in the manufacturing of many products, such as foam insulation, electronics equipment, refrigerators and air conditioners. When allowed to escape, these chemicals drift some 30 miles above the Earth to the stratospheric ozone layer - a layer of gas that screens us from the sun's powerful ultraviolet (UV-B) radiation. Once there, CFCs break apart - a process that releases chlorine, which then attacks ozone. A single chlorine atom can destroy more than 100 thousand ozone molecules.

The ozone layer is being depleted over Antarctica (the so-called Antarctic ozone hole), but also to a much lesser extent over North America, Europe, and other populated areas. A depleted ozone layer allows more UV-B radiation to reach Earth, harming human, animal, and plant life in many ways. Scientists around the world agree that increased UV-B radiation could over the long run cause a rise in cases of skin cancer and cataracts. Also, increased radiation could damage important food crops and marine ecosystems.

2. Protecting the Ozone Layer

The United States and over 126 countries are working together to protect the ozone layer by phasing out the production of ozone depleting substances in developed countries by the end of 1995. In addition, the Clean Air Act of 1990 contains requirements that ban the release of refrigerants during the service, maintenance, and disposal of air conditioning and refrigeration equipment and for labeling of products that are manufactured with or contain CFCs. To recover the CFC-12 used in vehicles, shops are required by law to use approved recover or recycling equipment when servicing air conditioning systems. Also, the technicians must be certified in the proper use of the equipment.



You can help save the ozone layer by getting professional vehicle service at a shop that uses recycling equipment and by having leaking systems repaired. Recycling and leak repair help to conserve CFCs and limits the release of the chemicals to the environment.

All automakers are responding to the CFC production phaseout by producing vehicles with an alternative refrigerant called HFC-134a. This refrigerant does not deplete the ozone layer because it does not contain chlorine. By the end of 1994, virtually all new cars, trucks and vans will be equipped with HFC-134a air conditioning systems.

3. The CFC Phaseout and Your Vehicle

The phaseout of the CFCs means that production of the chemicals will stop by the end of 1995, but it does not mean that you have to stop using or having your air conditioner serviced with CFC-12. While the available supply will be limited and the costs will certainly rise (in part due to a federal tax on CFCs), many vehicle owners will still be able to have their vehicle air conditioning units serviced with CFC-12 in the future. Here are some important points to keep in mind as the CFC phaseout nears.

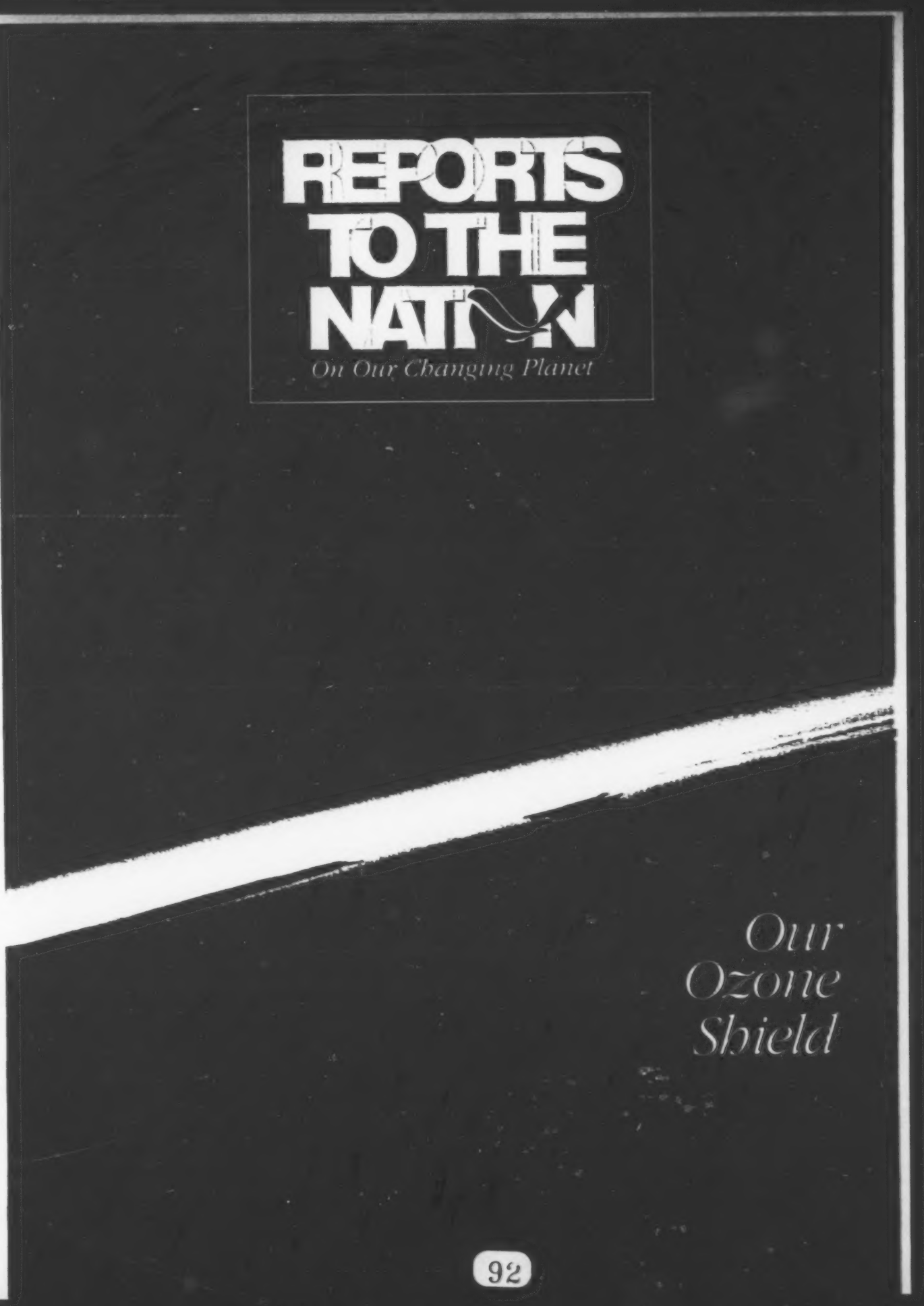
Reduce unnecessary loss of refrigerant. Preventive maintenance, fixing leaks, and recycling at service are key actions to minimize the need for additional CFC-12 refrigerant after the phase-out of production at the end of 1995.

Use only approved refrigerant. All vehicles that were designed for CFC-12 refrigerant should continue to use CFC-12 when serviced, unless the air conditioning system is modified to accept the HFC-134a alternative refrigerant. Using substances that have not been thoroughly tested may cause performance and safety problems and void your warranty.

Consider retrofit. You may decide that it makes sense to have your air conditioning unit modified to accept the HFC-134a alternative refrigerant. A good time to consider this is when you are having major service performed on your CFC-12 air-conditioner. Since the complexity and the cost of modifying a CFC-12 system will vary by vehicle make, model and age (the

REPORTS TO THE NATION

On Our Changing Planet



Our Ozone Shield

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REPORTS TO THE NATION
On Our Changing Planet

Our Ozone Shield

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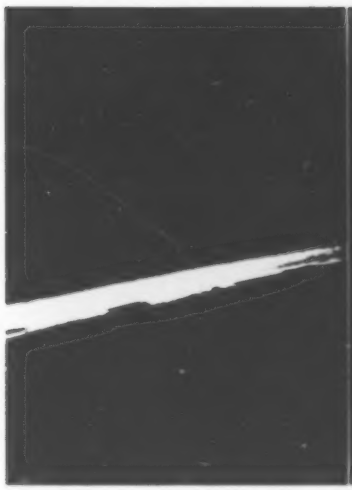
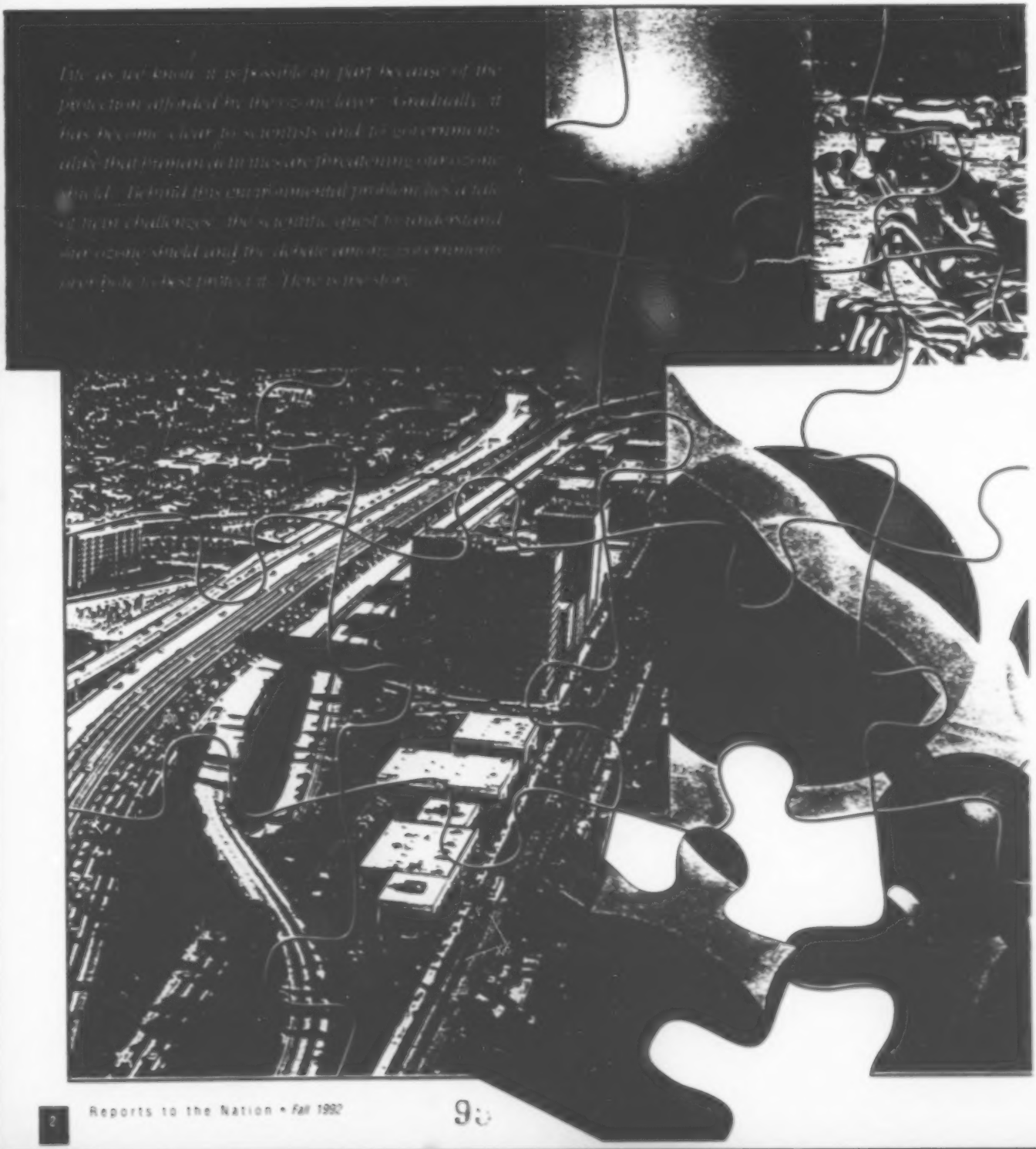
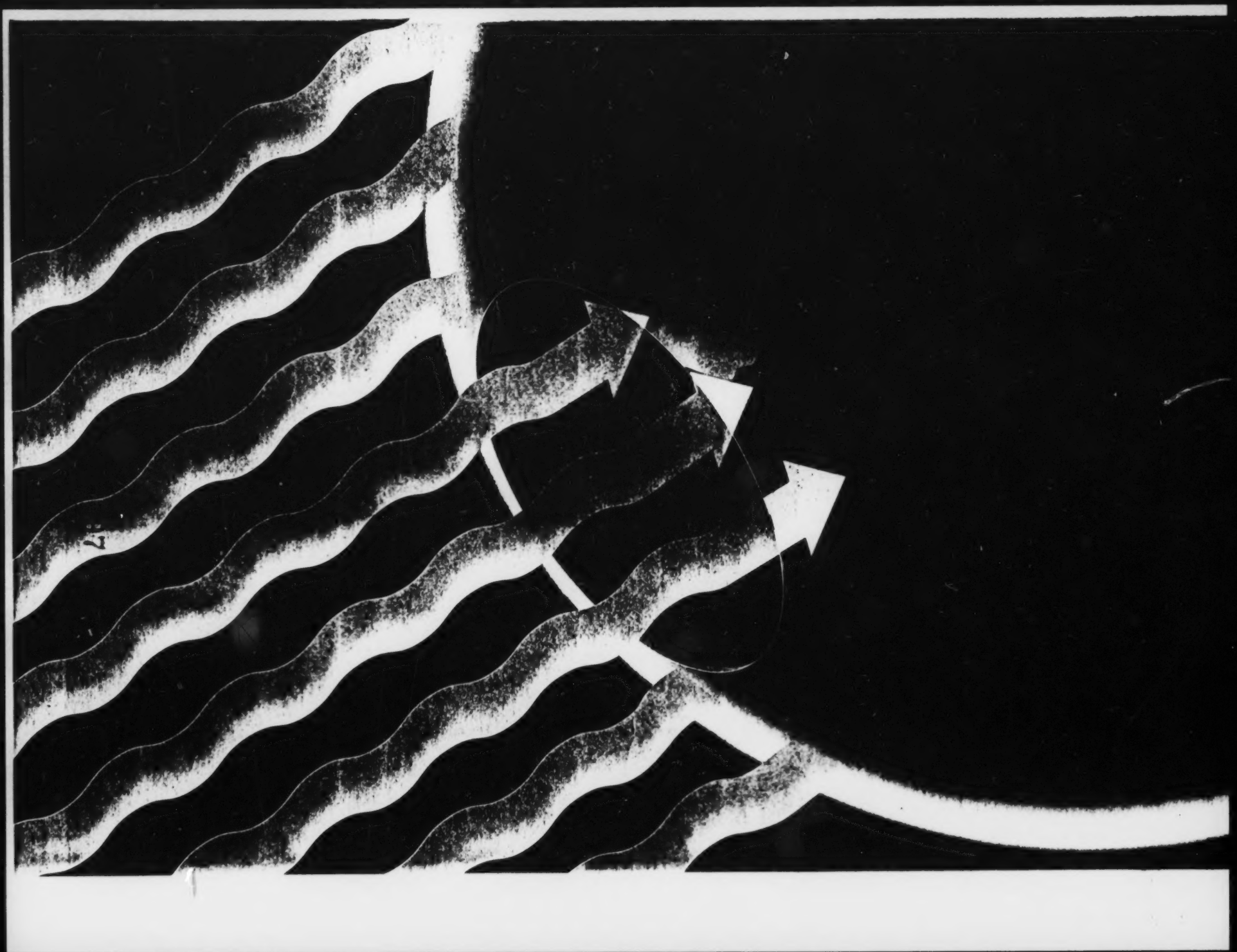


Orbiting above the Earth, an astronaut can look down on our home and see the thin blue ribbon that rims our planet. That transparent blanket—our atmosphere—makes life possible. It provides the air we breathe and regulates our global temperature. And it contains a special ingredient called ozone that filters deadly solar radiation.

Life as we know it is possible on Earth because of the protection afforded by the ozone layer. Gradually it has become clear to scientists and to governments alike that human activities are threatening the ozone shield. Behind this environmental problem lies a tale of keen challenges: the scientific quest to understand the ozone shield and the debate among governments over how to best protect it. Here is the story.





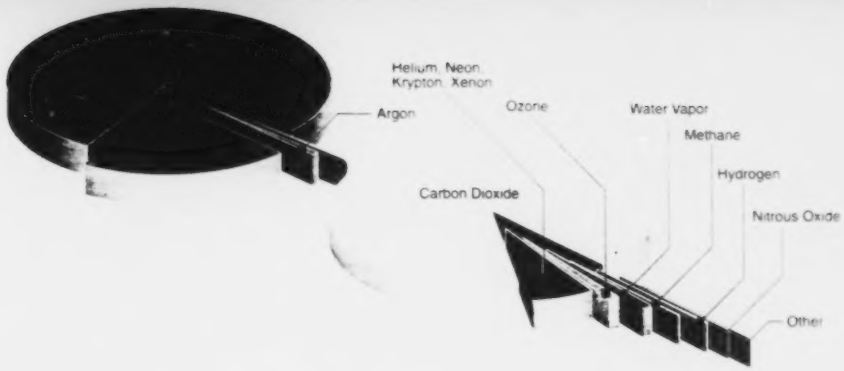
Our Ozone Shield

OZONE AND HUMANKIND. For nearly a billion years, ozone molecules in the atmosphere have safeguarded life on this planet. But over the past half century, humans have placed the ozone layer in jeopardy. We have unwittingly polluted the air with chemicals that threaten to eat away the life-protecting shield surrounding our world.

Although ozone molecules play such a vital role in the atmosphere, they are exceedingly rare: in every million molecules of air, fewer than ten are ozone. Nitrogen and oxygen make up the vast proportion of the molecules in the air we breathe. In this way, ozone resembles a critical spice in a pot of soup. Using just a few grains of a particular herb, a chef can season the whole pot with a distinctive flavor.

Ozone molecules show different character traits depending on where they exist in the atmosphere. About 90 percent of the ozone resides in a layer between 10 and 40 kilometers (6 and 25 miles) above the Earth's surface in a region of the atmosphere called the stratosphere. Ozone there plays a beneficial role by absorbing dangerous ultraviolet radiation from the sun. This is the ozone threatened by some of the chemical pollutants that we have released into the atmosphere.

Close to the planet's surface, however, ozone displays a destructive side. Because it reacts strongly with other molecules, it can severely damage the living tissue of plants and animals. Low-lying ozone is a key component of the smog that hangs over many major cities across the world, and governments are attempting to decrease its levels. Ozone in the region below the stratosphere—called the troposphere—can also contribute to greenhouse warming.



Although smog ozone and stratospheric ozone are the same molecule, they represent separate environmental issues, controlled by different forces in the atmosphere. This monograph will focus on the stratospheric ozone layer and the world's attempts to protect it.

What is ozone and where does it originate? The term itself comes from the Greek word meaning "smell," a reference to ozone's distinctively pungent odor. Each molecule contains three oxygen atoms bonded together in the shape of a wide triangle. In the stratosphere, new ozone molecules are constantly created in chemical reactions fueled by power from the sun. ☼

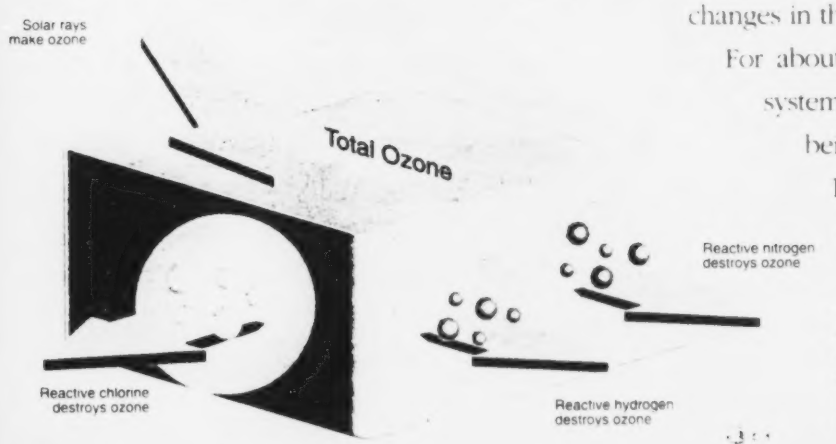
The recipe for making ozone starts off with oxygen molecules (O_2). When struck by the sun's rays, the molecules split apart into single oxygen atoms (O), which are exceedingly reactive. Within a fraction of a second, the atoms bond with nearby oxygen molecules to form triatomic molecules of ozone (O_3).

Even as the sun's energy produces new ozone, these gas molecules are continuously destroyed by natural compounds containing nitrogen, hydrogen, and chlorine. Such chemicals were all present in the stratosphere—in small amounts—long before humans began polluting the air. Nitrogen comes from soils and the oceans, hydrogen comes mainly from atmospheric water vapor, and chlorine comes from the oceans.

The stratospheric concentration of ozone therefore represents a balance, established over the aeons, between creative and destructive forces. The total level of ozone in the stratosphere remains fairly constant, an arrangement resembling a tank with open drains. As long as the amount of water pouring in equals the amount flowing out the drain holes, the water level in the tank stays the same.

In the stratosphere, the concentration of ozone does vary slightly, reflecting small shifts in the balance between creation and destruction. These fluctuations result from many natural processes such as the seasonal cycle, volcanic eruptions, and changes in the sun's intensity.

For about a billion years, the natural ozone system worked smoothly, but now human beings have upset the delicate balance. By polluting the atmosphere with additional chlorine-containing chemi-



The amount of ozone in the Earth's stratosphere is a balance between continuous production and loss. Ozone is produced by the sun's rays. It is removed by chemical reactions. But humans have added to the amount of reactive chlorine compounds in the stratosphere. Since the loss of ozone is now greater than the production of ozone, we are thinning our protective shield.

How does such a small piece play such a huge role?

cals, we have enhanced the forces that destroy ozone—a situation that leads to lower ozone concentrations in the stratosphere. The addition of these chemicals is the same as drilling a larger "chlorine" drain in the tank, causing the level to drop.

A Problem Arises: The Early 1970s

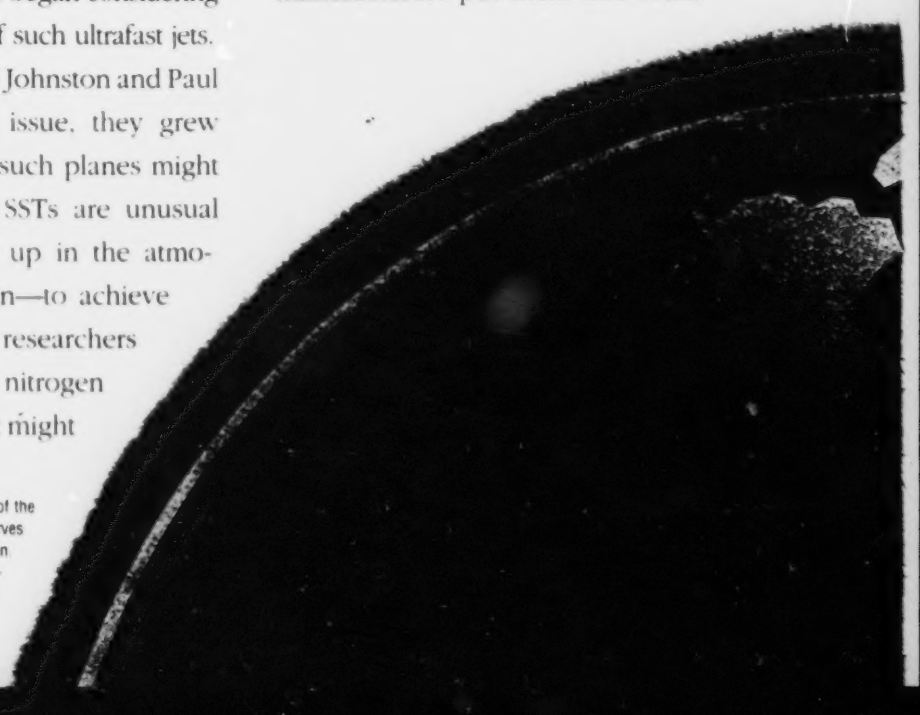
No one dreamed human activity would threaten the ozone layer until the early to mid-1970s, when scientists discovered two potential problems: ultrafast passenger planes and spray cans.

The plane threat surfaced first, after the invention of a new breed of commercial aircraft called supersonic transport (SST). These planes could fly faster than the speed of sound and promised to trim hours off long journeys. In the 1970s, the United States and other nations began considering whether to build large fleets of such ultrafast jets.

As scientists such as Harold Johnston and Paul Crutzen looked at the SST issue, they grew concerned about the effects such planes might have on the stratosphere. SSTs are unusual because they must fly high up in the atmosphere—where the air is thin—to achieve their fast speeds. Several researchers suspected that the reactive nitrogen compounds from SST exhaust might accelerate the natural chemical destruction of ozone, causing ozone levels to drop.

In 1974, news of another possible threat to the ozone layer made national headlines. This time scientists implicated a widely used class of chemicals known as chlorofluorocarbons (CFCs), which were most commonly known as the aerosol propellant in spray cans. Invented in the late 1920s, CFCs contain chlorine, fluorine, and carbon atoms arranged in an extremely stable structure.

Through decades of use, CFCs proved themselves to be ideal compounds for many purposes. They are nontoxic, noncorrosive, nonflammable, and unreactive with most other substances. Because of their special properties, they make excellent coolants for refrigerators and air conditioners. CFCs also trap heat well, so manufacturers put them into foam



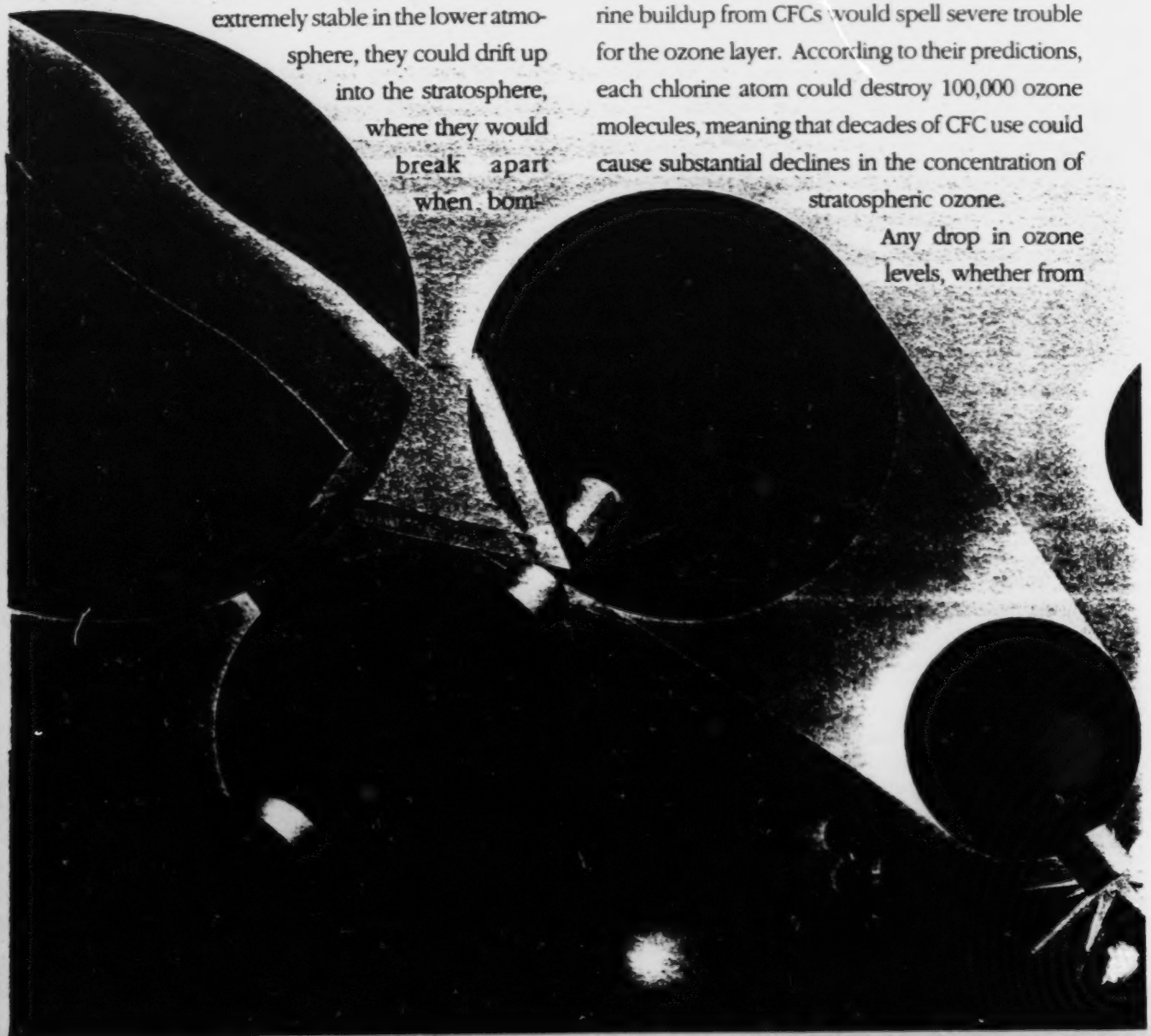
Most of the Earth's ozone is high in the upper part of the atmosphere—the stratosphere. This "good" ozone serves as our shield against incoming solar ultraviolet radiation. The "bad" ozone in the lower part of the atmosphere—the troposphere—adds to greenhouse warming and is a major part of smog in cities.

products such as cups and insulation for houses.

Most scientists had not worried about how CFCs would affect the atmosphere. But two chemists, F. Sherwood Rowland and Mario Molina, began considering these wonder compounds, and they uncovered something disturbing. Because CFCs were extremely stable in the lower atmosphere, they could drift up into the stratosphere, where they would break apart when bombarded by the sun's high-energy radiation. CFCs therefore carried millions of tons of extra chlorine atoms into the stratosphere, adding much more than the amount of chlorine supplied naturally by the oceans in the form of methyl chloride.

Rowland and Molina hypothesized that the chlorine buildup from CFCs would spell severe trouble for the ozone layer. According to their predictions, each chlorine atom could destroy 100,000 ozone molecules, meaning that decades of CFC use could cause substantial declines in the concentration of stratospheric ozone.

Any drop in ozone levels, whether from

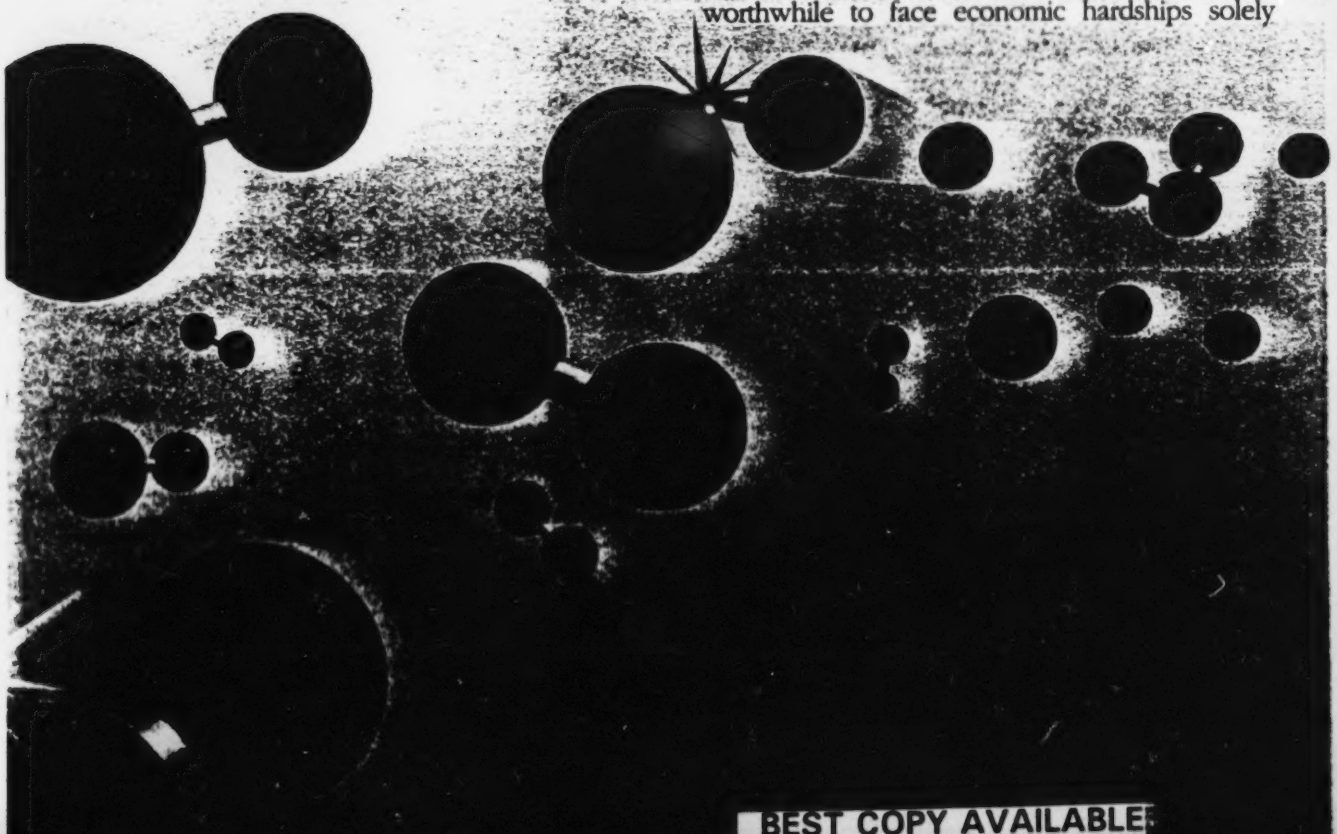


SSTs or CFCs, would allow more ultraviolet light to reach the Earth's surface—an effect that holds severe consequences for life on the planet. Exposure to ultraviolet light enhances an individual's risk for skin cancer and cataracts, so an increase in this radiation could lead to more cases of such diseases. Ultraviolet light also harms food crops and other plants, as well as many species of animals.

Thus the world faced two ozone-related environmental issues in the first half of the 1970s. In terms of SSTs, policy makers had to decide whether to build such planes. With CFCs, the question was whether to limit the production and use of these chemicals.

Of all the countries considering SSTs, the United States had planned the largest fleet, and it addressed this issue rather quickly. When preliminary scientific studies suggested the planes would significantly thin the ozone layer, the U.S. government decided against the proposed fleet.

Political leaders faced a much tougher decision on the subject of CFCs. For example, in the United States, these extremely reliable chemicals formed the center of a multi-billion-dollar industry. Though the Rowland/Molina hypothesis warned that CFCs might endanger the health of the planet's inhabitants, officials feared that a ban on such chemicals would disrupt many segments of society. Was it worthwhile to face economic hardships solely



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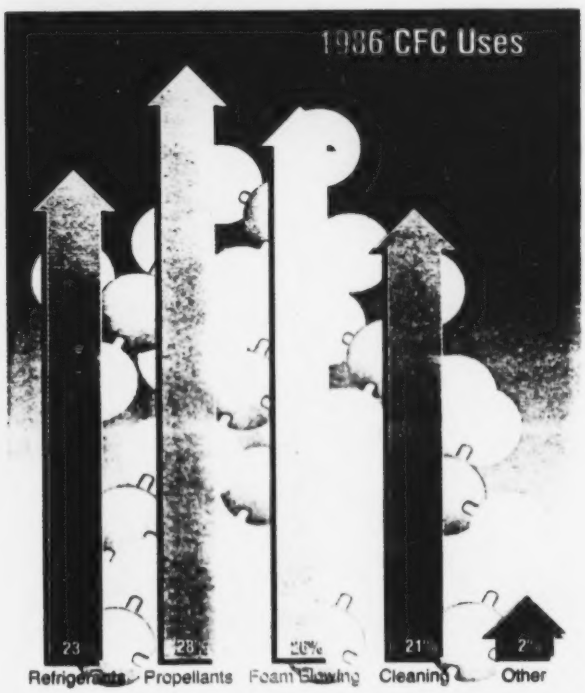
For millennia, ozone abundances varied naturally.

because of a scientific hypothesis and its predicted effects?

Decision makers also knew that the ozone layer belonged to the entire world, meaning that all countries would have to address the problem.

Stratospheric Ozone: The First Decade (1974–1984)

Would CFCs really bring significant harm to the ozone layer? That was the question politicians were asking in 1974, and the scientific community set out to provide an answer.



The human-made chlorofluorocarbons (CFCs) were "miracle" compounds. Their uses proved to be manyfold. They cooled refrigerators, propelled spray from cans, filled the insulating bubbles in foam, and cleaned delicate electronic parts. The rapid worldwide growth in the use of these ozone-depleting compounds in the mid-1980s rekindled international debate over whether their production should be curtailed.

Atmospheric researchers had to judge the seriousness of the problem. If ozone levels were to decline by only 1 percent in the next 50 years, nations would have little cause for concern. On the other hand, a substantial drop in ozone levels could jeopardize the world.

The first attempts to assess the problem produced dire forecasts, suggesting that CFCs could destroy perhaps half the ozone shield by the middle of the next century. Yet experts did not know how much to believe these early estimates, because they were based on a very simplistic understanding of chemical reactions in the stratosphere.

It was like trying to decipher a partially completed jigsaw puzzle, spread out on a table. Scientists wondered what the missing pieces looked like and whether they would change the emerging picture.

Over the next few years, researchers took many different routes toward filling in the gaps in the ozone puzzle. Experiments in the laboratory allowed chemists to gauge how quickly chlorine destroyed ozone molecules. Other scientists launched balloons that carried instruments up into the stratosphere, where they measured the concentrations of key chemicals that controlled ozone levels. All this information fed into new computer models that predicted how chemicals would affect the ozone layer.

By 1976, many experts had grown convinced that CFCs did indeed present a serious threat. In the United States—the world's largest producer and

but recently a downward trend has started.

user of CFCs—the public called for the government to place limitations on these chemicals. Civic leaders launched boycotts against items that used CFCs, and some companies even eliminated the compounds from their products.

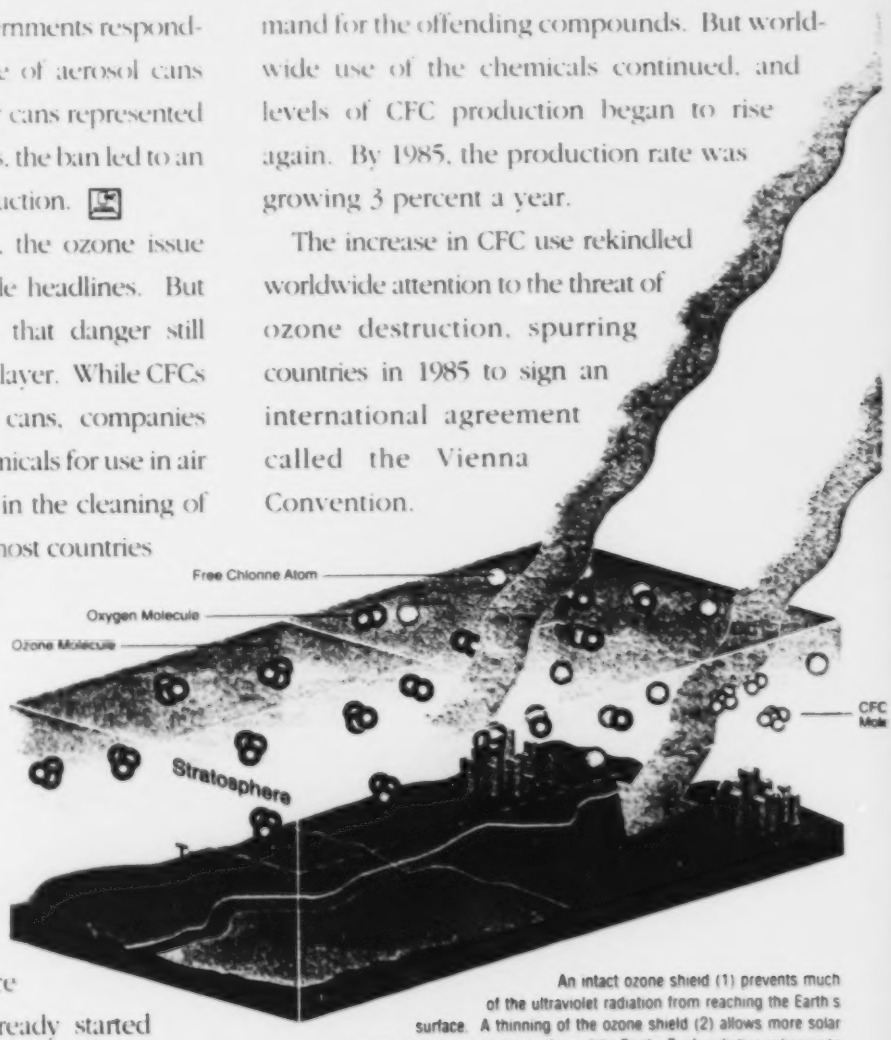
The U.S. and some other governments responded in 1979 by banning the sale of aerosol cans containing CFCs. Because spray cans represented the largest use of these chemicals, the ban led to an abrupt leveling off of CFC production.

After the spray can decision, the ozone issue quickly receded from worldwide headlines. But atmospheric researchers knew that danger still threatened the protective ozone layer. While CFCs no longer filled U.S. aerosol cans, companies continued to produce these chemicals for use in air conditioners, in insulation, and in the cleaning of electronic parts. What's more, most countries aside from the United States continued to use CFCs in spray cans. So even as the threat to the ozone layer slipped from the public spotlight, scientists extended their investigations into the problem.

Researchers also began watching the ozone layer more closely, searching for evidence that chlorine pollution had already started weakening the protective shield. They knew it might be difficult to spot such destruction at first. Ozone levels fluctuate naturally by several percent, so identifying the subtle signs of unnatural ozone loss would be like to trying to hear someone whisper a message across a crowded room.

The U.S. ban on CFC propellants in spray cans caused a temporary pause in the growing demand for the offending compounds. But worldwide use of the chemicals continued, and levels of CFC production began to rise again. By 1985, the production rate was growing 3 percent a year.

The increase in CFC use rekindled worldwide attention to the threat of ozone destruction, spurring countries in 1985 to sign an international agreement called the Vienna Convention.



An intact ozone shield (1) prevents much of the ultraviolet radiation from reaching the Earth's surface. A thinning of the ozone shield (2) allows more solar ultraviolet rays to reach the surface of the Earth. Such radiation is known to increase the number of skin cancers and cataracts in humans. It is also harmful to both terrestrial and aquatic ecosystems. Scientists in the 1970s were predicting that the impacts of such harmful ultraviolet radiation could become very significant indeed if humans continued to produce more and more CFCs.

The convention called on negotiators to draw up a plan for worldwide action on this issue. It also required scientists to summarize the latest information on the atmospheric consequences of CFCs and related bromine-containing chemicals called Halons, which had grown popular over the previous decade because of their ability to extinguish fires. Collectively, CFCs and Halons fit under the name halocarbons.

Using the most complete models, experts predicted that if levels of halocarbon production continued to increase as they had in the past, ozone concentrations in the stratosphere would drop by about 5 percent by the year 2050. Although much less severe than the predictions of earlier years, even a 5 percent decrease would still allow a very serious surge in the amount of ultraviolet radiation reaching the Earth's surface, causing millions of new cases of skin cancer in the United States alone.

By the time of the Vienna Convention, scientists remained uncertain whether ozone levels had actually started to drop. The research community, nonetheless, warned that countries could not afford to take a wait-and-see approach. Halocarbons present an insidious danger for the future because they can survive in the atmosphere for decades; some can last several centuries. That means even if the entire world stopped producing such compounds instantly, the halocarbons already in the atmosphere would continue to damage the ozone layer for more than 100 years. Many governments thought it critically important to limit the chemicals as soon as possible.

Then in May of 1985, shocking news spread throughout the scientific community. British researchers reported finding dramatic declines in ozone values over Antarctica each spring—actual "holes" in the ozone layer. Atmospheric scientists didn't know how to explain these large and unanticipated changes. Some proposed that natural processes were at work, while others thought it was the first sign that halocarbons were wearing away the protective ozone shield.

Despite uncertainty about the Antarctic phenomenon's cause, scientists firmly believed halocarbons would eventually deplete the global ozone shield. Their certainty and the jarring unexpectedness of the ozone hole's appearance motivated countries to act. In September 1987, diplomats from around the world met in Montreal and forged a treaty unprecedented in the history of international negotiations. Environmental ministers from 24 nations, representing most of the industrialized world, agreed to set sharp limits on the use of CFCs and Halons. According to the treaty, by mid-1989 countries would freeze their production and use of halocarbons at 1986 levels. Then over the next ten years, they would cut CFC production and use in half.

For scientists and policy makers, the Montreal Protocol marked a truly profound moment. When negotiators drew up the treaty, they were motivated by concerns about *future* ozone loss,

rather than by direct observations of current ozone destruction by CFCs. (Certainly the ozone hole in Antarctica had unnerved world leaders, but it was by no means clear whether chemical pollutants had caused this decline.) Thus, the agreement was based primarily on confidence in a theory.

The Montreal Protocol established a new way of viewing environmental problems. In the past, the world had addressed such issues only after damage grew noticeable. For example, nations agreed to limit above-ground nuclear tests once it became evident these explosions poisoned the air and water with radioactivity. The Montreal agreement, however, tackled the ozone issue early, demonstrating a heightened sense of environmental responsibility.

The framers of the protocol also broke new ground in another way: they realized their agreement might not suffice if future scientific work revealed that the ozone layer faced even greater danger. Uppermost in their minds was concern over the Antarctic ozone hole and its possible implications for global ozone. The diplomats therefore included a provision calling for negotiators to reconvene in 1990 to examine any new scientific or technical information that might necessitate adopting deeper cuts.

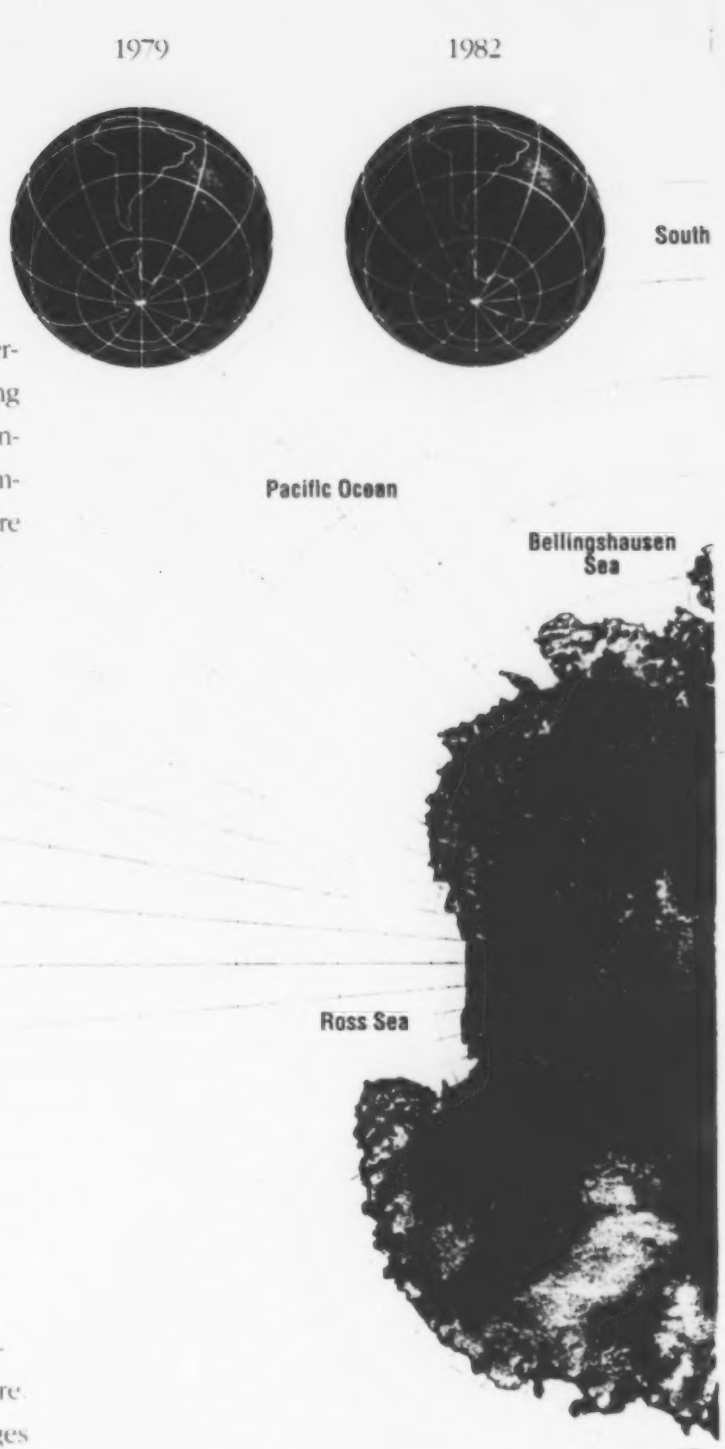
After it was hypothesized that CFCs could destroy ozone, researchers focused on quantifying this theory. Some hoisted instruments into the stratosphere with huge balloons. Others probed the inner workings of the ozone-destroying chemical reactions in the laboratory. Still others crafted all of this information into computer models, which foretold mounting ozone losses if CFC usage continued to grow.

The Ozone Years: 1985–1989

The ozone hole was born in the late 1970s, long before the Montreal Protocol was signed. Like a leak in the roof over the distant part of a house, the hole at first grew unnoticed by any human being living below.

Each spring, ozone abundances over the ice-covered continent dropped below normal and then rose gradually toward normal amounts in summer. And each year, the springtime losses grew worse.

A British team, which had measured ozone levels over the Antarctic coast since 1956, first began noticing the phenomenon in the early 1980s. But it was hard to swallow the evidence at first. Was the ozone hole real, or were the instruments malfunctioning? wondered the scientists. After checking and rechecking the instruments, the British researchers grew confident of their discovery. In 1985, they announced their startling news to the rest of the world.



Atmospheric experts moved quickly to determine whether the ozone hole was real. Consulting measurements made by satellite-borne and balloon-borne instruments, they found evidence confirming the springtime ozone depletion. Even more staggering, measurements showed the hole extending over the entire Antarctic continent.

The discovery of the ozone depletion blindsided the scientific community, catching it totally off guard and without a suitable explanation. But within a few months, theoretical scientists came up with three competing ideas that could explain why the ozone hole had developed over Antarctica.

One group of scientists focused on the solar cycle—the periodic waxing and waning of the sun's energy output. Noting that solar radiation had grown particularly strong in the early 1980s, some researchers proposed the intense radiation had created above-normal levels of reactive nitrogen chemicals in the stratosphere. These compounds could then concentrate over Antarctica and destroy ozone there.

A second group suggested that natural changes in stratospheric winds were responsible. According to this "dynamical" theory, the ozone hole resulted from changes in the system of air motions that transport ozone and establish its amount in the polar regions.

Antarctica—the "last place on Earth." But here occurred the first large-scale ozone losses. British scientists discovered that, in the mid-1970s, the ozone layer over Antarctica began to thin during each springtime. By the mid-1980s, the magnitude of these seasonal losses had grown to 50 percent, which was much greater than any known natural variation. The Antarctic ozone "hole" had been discovered, presenting both scientists and policy makers with a complex puzzle.

Both the solar cycle and dynamical theories stressed natural processes as a cause for the depletion. But a third theory held that human-made chemicals deserved blame. According to this idea, the cold conditions above Antarctica amplified the ozone-destroying power of CFCs and Halons, accelerating the loss in this region.

The three separate theories held profoundly different implications for the world. If halocarbon pollution created the hole, then scientists had gravely underestimated the chemicals' destructive power, and the ozone layer faced even more danger than previously thought. But if the hole formed because of natural processes, then humans could breathe a sigh of relief.

With very little known about the Antarctic ozone losses, atmospheric researchers could not tell which theory was correct. Yet they recognized that political leaders would need an answer as soon as possible. The signers of the Montreal Protocol would be meeting to review the limitations on halocarbons, and it was critical to know whether these chemicals lurked behind the ozone hole.

The scientific community threw itself at the problem, launching several field expeditions aimed at solving the riddle of the ozone depletion. In September of 1986, a hastily assembled team hurried off to McMurdo Station in the Antarctic. Using ground-based instruments and balloons to probe the stratosphere, this team found high levels

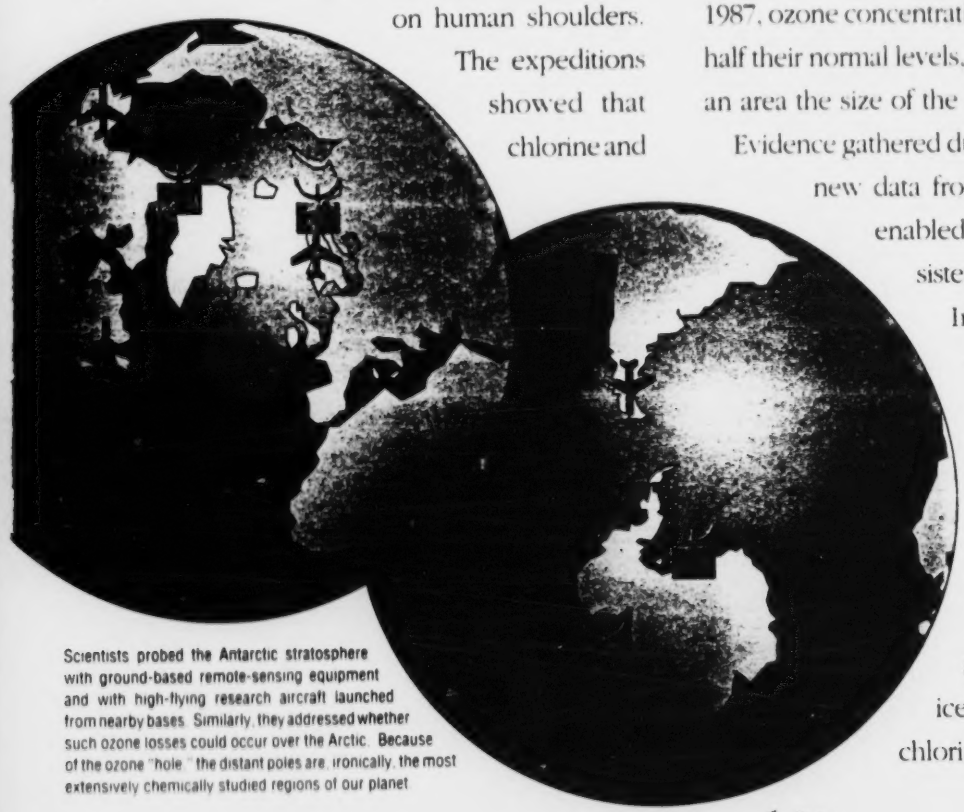
Sunspots?

of ozone-destroying compounds. A year later, the United States, in conjunction with other countries, sent a massive group of more than 100 scientists, engineers, and technicians to Punta Arenas, Chile, at the southern tip of South America. From this distant base, two research airplanes flew into the dangerously cold Antarctic sky to gather conclusive data about the mysterious affairs in the stratosphere over that icy land. Other scientists returned to McMurdo for further measurements.

By October 1987, the researchers came back from the Southern Hemisphere with a dark message for the world: blame for the ozone hole falls on human shoulders. The expeditions showed that chlorine and bromine pollution had shifted the fragile chemical balance in the Antarctic, thereby draining those skies of ozone during the spring.

Ozone loss is accelerated over the frozen continent because the Antarctic stratosphere contains cloud particles not normally present in warmer climes. These icy particles have a critical effect on the chlorine and bromine pollution floating in the stratosphere. Normally, the chlorine and bromine are largely locked into "safe" compounds that cannot harm ozone, but the ice particles transform them into destructive chemicals that can break apart ozone molecules with amazing efficiency. In 1987, ozone concentrations above Antarctica fell to half their normal levels, and the hole spread across an area the size of the United States.

Evidence gathered during these expeditions and new data from laboratories back home enabled scientists to fashion a consistent theory to explain the hole. In the prelude to ozone depletion, ice particles form during the polar night, when several months of darkness descend on Antarctica and temperatures plummet below -80°C (-112°F) in the stratosphere. On those floating ice particles, reactions convert chlorine from the "safe" to the



Scientists probed the Antarctic stratosphere with ground-based remote-sensing equipment and with high-flying research aircraft launched from nearby bases. Similarly, they addressed whether such ozone losses could occur over the Arctic. Because of the ozone "hole," the distant poles are, ironically, the most extensively chemically studied regions of our planet.

Meteorology?

Chemistry?

"destructive" form. The real action begins when the sun returns to this part of the world during springtime, energizing the chemical cycle that destroys ozone. Wind patterns during winter and spring contribute by isolating the Antarctic stratosphere from warmer air to the north.

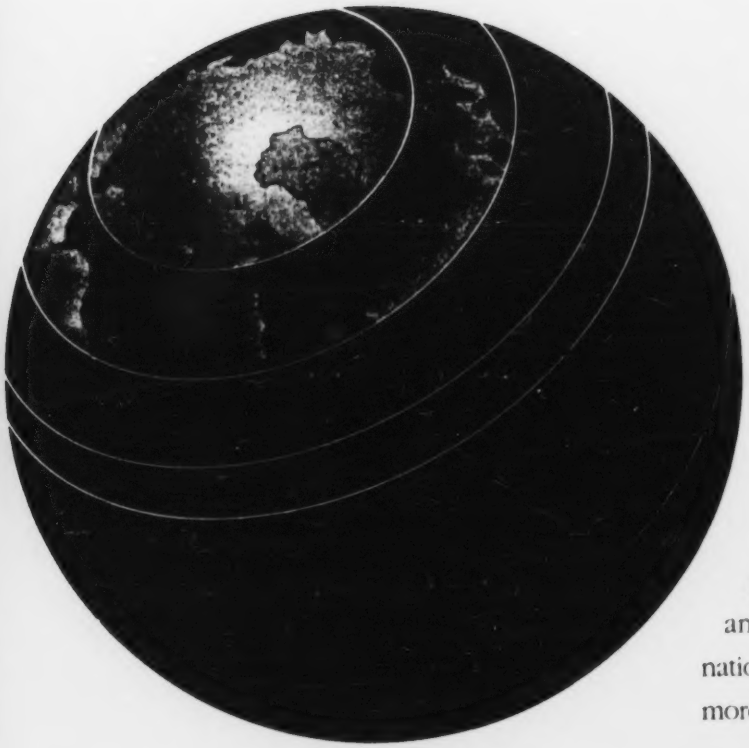
The ozone hole forms only in Antarctica because this region has a unique combination of weather conditions: it is the coldest and most isolated spot on Earth. But somewhat similar conditions exist in the Arctic, and scientists wondered whether the North also suffered from ozone loss. Even small depletions in this region would represent cause for concern, because many people live in northern latitudes potentially affected by Arctic ozone loss. So in 1988, two small teams traveled to Greenland and Canada to gather data. A year later, an extensive group headed to Norway to take measurements with the two airplanes that helped to solve the Antarctic puzzle.

The northern expeditions revealed that during wintertime, the Arctic stratosphere has the same types of destructive chlorine and bromine compounds that cause the problems in the Antarctic. Indeed, when scientists returned to the Arctic for an extended study in 1991 and 1992, they discovered strong hints that such compounds had destroyed significant amounts of ozone in the polar region. But because the Arctic atmosphere is not as isolated, the ozone losses there appear to be much smaller than those in Antarctica—at least for the present.

Between trips to the ends of the Earth, atmospheric scientists during this period also stepped up their search for signs of a global erosion in the ozone layer. An international panel of experts came together to scrutinize measurements made by satellites and by ground-based instruments around the world. In 1988, they reached a verdict: global ozone levels *had* declined over the past 17 years, mainly in the winter. Normal processes such as the solar cycle had caused part of the drop, but natural effects could not explain the entire ozone loss.

The news grew even worse. An international panel announced that ozone levels had dropped by measurable amounts not only in winter and spring but also in summer. Because people spend far more time outdoors during summer, ozone loss at this time of the year poses the greatest threat to the health of humans.

Scientists suspect that CFCs and Halons are to blame for much of the ozone decline, which has reached several percent over the midlatitudes of the Northern Hemisphere—the segment of the globe that encompasses the United States and Europe. But atmospheric researchers are not yet fully confident that they know what mechanism lies behind the drop. The largest changes have occurred over the poles and neighboring midlatitudes, leading some researchers to suggest that loss near the poles has enhanced the decline in global ozone levels. Others suspect that the



Spurred by the CFC – ozone hypothesis, scientists began closely watching the variations in global ozone, searching for the first sign of the predicted ozone losses. In the late 1980s, they began to see ozone losses, even outside of the polar regions, that could not be explained by natural variation. These losses, which increase poleward from the equator, appear to be related to the CFCs, but the details are not yet fully explained.

natural, thin layer of sulfur-containing particles in the stratosphere could be involved in midlatitude ozone loss, in a role somewhat similar to that played by ice particles over Antarctica.

The fast-paced research of the late 1980s revealed that the original Montreal Protocol would not go far enough toward protecting the fragile ozone layer. Even with the 50 percent cuts mandated by the treaty, levels of chlorine and bromine would still rise in the stratosphere, meaning that ozone loss would only worsen with time.

In June 1990, diplomats met in London and voted to significantly strengthen the Montreal Protocol. The treaty calls for a complete phaseout of CFCs by the year 2000, a phaseout of Halons (except for essential uses) by 2000, and a rapid phaseout of other ozone-destroying chlorine compounds (carbon tetrachloride by 2000 and methyl chloroform by 2005).

The treaty also attempts to make the phaseouts fair for developing countries, which cannot easily afford the higher-priced substitutes that will replace banned compounds. The revised agreement establishes an environmental fund—paid for by developed nations—to help developing nations switch over to more "ozone-friendly" chemicals.

Our Ozone Layer: Present and Future

But many pieces of the ozone puzzle remain missing, and scientists wonder whether new ozone problems will develop in the near future. Experts are exploring several unanswered questions, including:

- What surprises lurk in the next decade or so? Even with the amended protocol, chlorine abundances will continue to rise until around the turn of the century.
- Will ozone losses grow worse in the Arctic as chlorine abundances increase?
- How safe are the CFC substitutes? Will some of them significantly contribute to ozone loss, global warming, or other environmental problems?
- How appropriate is it to allow countries to continue "essential" uses of the powerful ozone

For the first time in my life I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light—our atmosphere. Obviously this was not the ocean of air I had been told it was so many times in my life. I was terrified by its fragile appearance.

Ulf Merbold, German Astronaut

depleting Halons? The current treaties permit these uses.

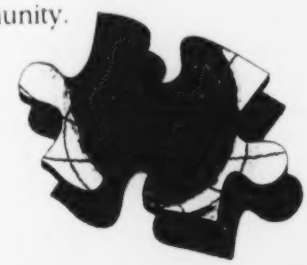
- Are there other compounds that significantly deplete the ozone layer and hence could deserve attention under the Montreal Protocol—such as methyl bromide, which is used widely as a fumigant?
- How will polar ozone destruction affect populated countries? Will the Antarctic hole cause ozone declines over Chile, Argentina, and New Zealand? Will Arctic losses spur drops in ozone concentration over Canada, Scandinavia, the United States, and the former Soviet Union?
- How much do the natural particles in the stratosphere, other than the icy polar clouds, accelerate the chemical destruction of ozone at midlatitudes?
- How will large volcanic eruptions—which can inject immense amounts of dust into the stratosphere—affect the ozone layer when the chlorine from CFCs reaches unprecedented abundances?
- How will the ozone hole and global ozone losses affect worldwide weather and climate?
- Does a proposed new class of high-altitude aircraft threaten the ozone layer?

Decision makers will need answers to such questions as they continue to revisit their international agreements in the future and ask if these are adequate in light of new research findings.

The Montreal Protocol provides a dramatic example of science in the service of humankind. By quickly piecing together the ozone puzzle, atmospheric researchers revealed the true danger of halocarbons, allowing world leaders to take decisive action to protect the ozone layer.

This international agreement represents a critical step toward saving the world's ozone layer. But perhaps more importantly, it has taught scientists and policy makers an invaluable lesson about addressing environmental problems. Negotiations on this issue mark the first time the nations of the world have joined forces to protect the Earth for future generations.

The treaty can serve as a crucial apprenticeship for world leaders and scientists, who now face an even more daunting environmental matter—the threat of global greenhouse warming that looms over the future of this planet. The successful ozone agreement offers hope that scientific understanding can once again provide the foundation for responsible action by the international community.



Understanding our global environment

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Our Ozone Shield is the second in a series of publications on climate and global change intended for public education. They are a joint effort of the UCAR Office for Interdisciplinary Earth Studies and the NOAA Office of Global Programs, for the purpose of raising the level of public awareness of issues dealing with global environmental change. The reports are written by knowledgeable scientists and science writers on timely subjects and guided by a scientific Editorial Board. The first in the series, *The Climate System*, appeared in winter 1991.

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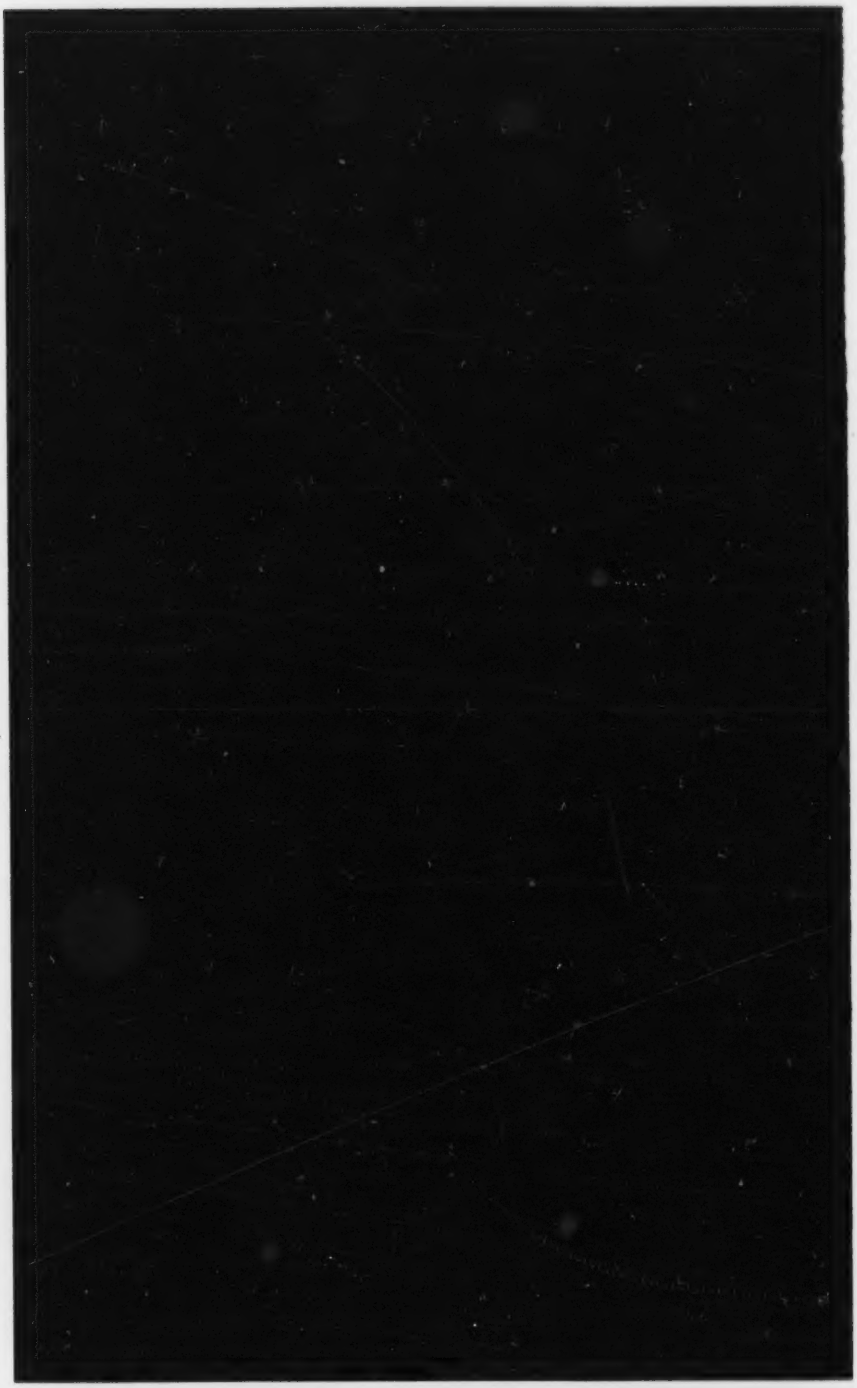

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and our role in it is the first step toward living in better harmony with nature.

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OZONE LAYER EDUCATOR RESOURCES: UPDATE

1. The NOAA CD-ROM and Computer Discs listed contain the same material. Both are essentially exercises in Geophysical Information Systems (GIS) with emphasis on vegetation, precipitation, soils etc. The CD sells for $91; the disc set is $150. A teachers guide is in preparation.

2. It is not known whether the Australian Bureau of Meteorology will send copies of their brochure on ozone. Also, as they are 14+ hours ahead of the U.S., calling by phone will be extremely difficult.

3. The address correction for Hank Robinson (NOAA/NWS) is:

1335 East-West Hwy, SSMC-2
Room 13305
Silver Spring, MD 20910
Fax (301) 589-1321

4. There are no copies available of the NOAA/OGP Reports to the Nation: "The Climate System". The correct address to write for the other monographs in the series is:

Paula Robinson
UCAR/JCIP-PO
P.O. Box 3000
Boulder, CO 80307
(303) 497-8665
Fax 497-8663

Earth's *Changing* Atmosphere
Investigating Its *Mysteries*!

The Mystery:

The great mystery surrounding us is this:

How does the atmosphere *work*?

- ✔ **What processes are involved, and how do these processes affect each other?**
- ✔ **How does the Sun influence the chemistry of the atmosphere?**
- ✔ **As the human population increases, are we causing change to occur at a faster rate?**
- ✔ **Is this change positive or negative?**
- ✔ **What changes can be expected in the future, and will those changes seriously affect our lives?**

We need to understand how the parts of our environment work together if we are to answer these and similar questions and protect Earth's atmosphere for the future.

A mystery story is unfolding around us.

It involves the entire system that makes life on Earth possible, and it is one of the most important puzzles that has ever faced Earth's citizens. The **environment** in which we live is a very complex system, made up of our **atmosphere**, **oceans**, and **land masses**, as well as all the **plants** and **animals** that inhabit the planet. Even the **Sun** is part of this system. ***Each of these individual parts affects the others***, creating a **balance** that has sustained life for many years.

We know that one of these important parts,

our **atmosphere**, ***is changing***.

Carbon dioxide, one of the atmospheric gases that lets **sunlight** through to Earth's surface, yet prevents heat from escaping to space, has increased over the past century. **Ozone**, which blocks dangerous **ultraviolet** (UV) radiation from the Sun, is becoming thinner in some latitudes. Even the amount of energy radiated by the Sun fluctuates.

Solving the Mystery:

The *United States Global Change Research Program* is this country's effort to provide some of these answers by investigating Earth from its inner core to the outermost edges of the atmosphere. Investigators studying oceanography, geology, atmospheric chemistry, solar activity, clouds, precipitation, and weather are participating.

NASA is contributing to the study through a program called **Mission to Planet Earth** (MTPE), which has been established to examine the changes in the delicate balance between sunlight, atmosphere, water, land, and life on Earth. For years, scientists on Earth have studied other planets. Now some of these atmospheric detectives are studying our planet and its atmosphere from **satellites** in space or during **Space Shuttle** missions, gathering clues to help solve the mystery. Other investigators are making observations from **balloons** and **airplanes** or working in **laboratories** on the ground. Scientists from different fields of study and from many countries are participating in this investigation, sharing information as they work together to unravel the **puzzle** of **Earth's complex atmosphere**.

The **Atmospheric Laboratory for Applications and Science (ATLAS) Space Shuttle missions** are part of NASA's **Mission to Planet Earth, studying atmospheric chemistry and the interactions between the Sun and Earth's atmosphere**. Researchers working on each mission collect data, building a comprehensive ***library of information*** on the atmosphere. In addition, data gathered during these missions are used to verify measurements taken by the Upper Atmosphere Research Satellite (UARS). This and related research are used with continuing ground, balloon, and aircraft observations to help these atmospheric detectives **discover the causes and solutions to some of our planet's problems**. ***The third ATLAS mission is scheduled for late 1994.*** The first two flights (in 1992 and 1993) allowed scientists to measure the largest number of atmospheric chemicals that have ever been measured over a large part of the globe. The ATLAS 1 mission occurred shortly after the eruption of the ***Mt. Pinatubo volcano***, and investigators were able to observe how the chemicals that were spewed into the air had affected the ozone layer. **Also, solar scientists are studying the energy emitted by the Sun *(the solar irradiance)*** that reaches Earth's surface. Instruments aboard satellites have been making these measurements for years, but as they absorb energy from the Sun, their performance is degraded and measurements become less accurate and less precise. On the ATLAS missions, investigators have been able for the first time to fly the same solar instruments several times and to check their accuracy and precision after each flight. They use these calibrations to check the satellite instruments, which they cannot retrieve. During the ATLAS 2 mission, solar instruments located on the Space Shuttle and similar instruments on satellites measured the solar irradiance at the same time, achieving the most definite measurement yet for the solar irradiance.

Your Part:

All these efforts are critical to you, today's students, for you will be most affected by any continuing change of our planetary home. Some of you will be the scientists and researchers of tomorrow, but **it is vitally important that all of you become informed citizens capable of making wise decisions about environmental issues affecting your lives.**

Why Study the Atmosphere?

Earth's atmosphere is a precious natural resource.

It provides air to breathe and **regulates the Sun's energy** to heat and cool the planet. It **filters the Sun's rays**, allowing those that provide heat and light to reach Earth's surface while blocking those that are harmful. It also **recycles water** and other chemicals. **Without this protective blanket, we could not survive.**

Provider:

The atmosphere is made mainly of nitrogen and oxygen, with traces of carbon dioxide, water vapor, and other gases.

Human beings can survive only about ***5 minutes*** without this air, but because it is always there, odorless, tasteless, and invisible, we take it for granted. If you have ever flown in an airplane, you have heard instructions for putting on an oxygen mask in case the cabin loses pressure. If that were to happen, the normal atmosphere of the airplane would be lost, exposing you to the very thin air at that altitude. **Humans and other animals cannot survive without oxygen; plants cannot survive without carbon dioxide**. The atmosphere provides these essential gases.

Blanket:

Even if we wore oxygen masks, we still could not stay alive without Earth's atmosphere.

Right now, the **global mean temperature** of Earth, the average of all temperatures around the globe throughout the year, is **15 °C**. If we did not have the atmosphere, Earth would be very cold, probably too cold for us to be able to live here. ***Water vapor, carbon dioxide, and other gases in the atmosphere act like a blanket***, holding in the heat that is generated when sunlight reaches Earth's surface. **This makes Earth the only planet in the solar system to support life, as far as we know.** Too much heat is not good either, and the **clouds** in Earth's lower atmosphere reflect the Sun's visible light, helping to keep the planet's surface from becoming too warm.

Sunscreen:

The atmosphere is also Earth's "sunscreen."

The wavelengths of energy given off by the Sun vary from the long, low-energy radio waves to the very short, highly energetic waves of gamma rays. The atmosphere is transparent, like glass, to **radio waves**, shorter **infrared rays**, and **visible light** traveling to Earth from the Sun. *Fortunately*, the atmosphere ***blocks*** all the ***deadly*** **gamma rays** and **X-rays**, and most of the harmful **ultraviolet radiation**, which can burn skin and eyes and cause skin cancer!

Recycler:

The Earth-system was the original recycler!

Carbon dioxide and oxygen are recycled by plants and animals. During photosynthesis, **green plants use carbon dioxide to make food and release oxygen. Animals use the oxygen produced by plants and exhale carbon dioxide**. ***Water is also recycled***, continually *evaporating* from bodies of water on Earth and then *cooling and condensing* in the atmosphere to fall to Earth again as **rain, snow, or sleet**. Chemicals, too, find their way into the atmosphere from Earth. Volcanoes spew ash and gases that were formed deep within the planet into the air. There they react with other chemicals, form small airborne particles called **aerosols**, and move from one atmospheric layer to another until they return to Earth's surface in rain or other precipitation. *Burning, construction, and industrial processes, as well as natural wind erosion and sea spray, also add chemicals to the atmosphere.*

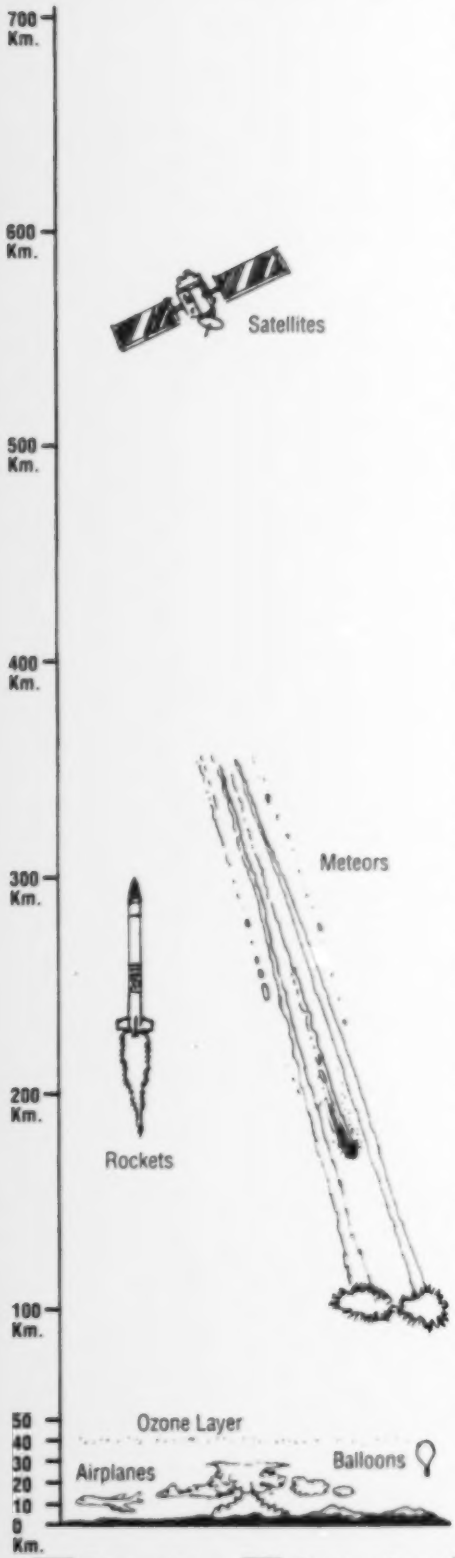
Changes?

Today, scientists are concerned because the amounts of some chemicals in our atmosphere are changing. Gases released by *industry, agriculture, and other human activities* are building up in the lower atmosphere and could enhance the atmosphere's warming influence, perhaps leading to temperature changes with long-range effects. **Ozone**, a gas in the stratosphere that acts as a natural screen for dangerous radiation, ***is being destroyed*** by other human-made compounds. Researchers have also wondered if the Sun's output is changing, which could lead to temperature changes on Earth. ***What will be the outcome of all these changes?*** Scientists form theories, but they cannot be sure.

ATLAS scientists are part of the team of investigators from all over the world who are studying Earth's atmosphere and monitoring the output of the Sun to solve these mysteries and provide answers for many of the environmental problems that face us today and may affect our lives tomorrow.

Going Up!

What is the **structure** of the atmosphere?



Troposphere Stratosphere Mesosphere Thermosphere

Earth has a "**blender**" atmosphere: except at high altitudes, the chemicals in it are well mixed by **rising and sinking air**.

Lower Atmosphere:

The part of the atmosphere that you can reach out and touch is the **troposphere**, the lower part of the atmosphere where most clouds and weather occur. ***Humans live at altitudes up to about 4 km***, and the troposphere extends further upward another ***6 to 11 km***. At the top of the troposphere, about 10 to 15 km above Earth's surface, is the **tropopause**, which divides the troposphere from the next layer of the atmosphere.

Middle Atmosphere:

Above the tropopause is the **stratosphere**, which rises to about ***50 km*** above Earth. In this layer, **ozone**, a special form of oxygen, ***absorbs and scatters the Sun's harmful ultraviolet radiation***. The ozone concentration is controlled by many chemical processes and can only be understood if scientists understand the full details of the many chemical reactions that occur in this important region. The stratosphere and the next layer, the **mesosphere**, are called the middle atmosphere. The mesosphere begins just above the stratosphere and extends to ***85 km*** above Earth. At about ***100 km***, primary ingredients in the atmosphere, such as nitrogen and oxygen, become less well mixed. **The middle atmosphere is the region studied by investigators during the ATLAS Space Shuttle missions.**

Upper Atmosphere:

Above the mesosphere is the **thermosphere**, which reaches to about ***600 km*** above our planet's surface. The *air in the lower part of the thermosphere is very thin* — only one ten-millionth (0.00000001) as dense as the air at sea level.

A unique region called the **ionosphere** begins toward the top of the mesosphere and extends to the ***top of the thermosphere***. In this region, there are many electrically charged particles called **ions**. **Radio waves can be bounced off the negatively charged ions (electrons)** to send messages to distant parts of Earth. *When bursts of energy erupt from the Sun (solar flares), the ionosphere is disturbed*, and radio, telephone, and TV satellite communications can be disrupted.

Earth's **magnetic field**, called the **magnetosphere**, extends beyond the thermosphere ***into the vacuum of space***. On the side of Earth facing the Sun, the magnetosphere extends outward to approximately ***9,660 km*** beyond Earth's surface. On the opposite side, where Earth's face is in darkness, the magnetosphere extends ***much farther***.

Temperatures:

Because mountaintops are often covered with snow, most of us think that temperatures drop as we go higher into the atmosphere. This is true, up to a point. Within the **troposphere**, temperatures drop from about ***17 °C*** to about ***-52 °C***. At the **tropopause**, the decline in temperatures "**pauses**": temperatures stay about the same as in the troposphere. In the **stratosphere**, **ozone absorbs ultraviolet light**. The energy from this reaction gives off heat, causing temperatures to **gradually climb back up** to ***-3 °C***. Above the stratosphere is the **mesosphere**, where the **coldest temperatures** in the atmosphere are found, dropping to ***-93 °C***. **The next layer warms again**: temperatures in the **thermosphere** may reach ***1,727 °C***.

Activity:

Materials Needed:

✔ **pencil** ✔ **colored pencils**

Procedure:

On the left side of the chart, there are various altitudes shown. **Draw horizontal lines** to show where each atmospheric layer begins and ends, and label the layers. Now **choose colors** to represent each layer. Color the layers. Be sure to color and **label** the "Key" shown below the chart.

Questions:

❶ Which layer is the warmest? What color would be appropriate?

❷ Which layer is the coldest? What color will you make it?

❸ What colors will you choose for the remaining layers?

❹ For the ATLAS missions, the Shuttle orbits about 296 km above Earth. In which layer does it travel? Draw the Shuttle on the chart at the correct altitude.

❺ Which layers does ATLAS study?

What a Gas!

The **atmosphere** is like an **ocean of air** that surrounds Earth. It is held to Earth by the pull of gravity, and it travels with Earth as the planet moves through space. Studies show that the lower atmosphere is a uniform mixture of gases that are constantly recycled. Animals breathe in **oxygen** and breathe out **carbon dioxide**. Plants use **carbon dioxide** to make food, and they release **oxygen**. **Nitrogen** is used by plants and by microorganisms that live in the soil. **These gases make life on Earth possible.**

Nitrogen makes up 78 percent of Earth's air. Oxygen makes up 21 percent. The remaining 1 percent is **water vapor**, **carbon dioxide**, **argon**, and **other trace gases** — *those that exist in very small amounts*. Some of these, water vapor, carbon dioxide, methane, nitrous oxide, and ozone, are the gases that trap energy and warm Earth. They make up only **1 percent** of the gases in the **lower atmosphere**, but they are very effective heat collectors.

Activity A:

For a colorful view of this "**air soup**," try this activity:

Materials Needed:

- ✔ **one 340-g package of dried kidney beans**
- ✔ **one 340-g package of popcorn**
- ✔ **one 340-g package of dried green peas**
- ✔ **one 1-ℓ glass jar with lid**

(There will be enough beans, peas, and popcorn to fill several jars.)

Procedure:

Air is not usually measured in cups or ounces, so imagine that you want to mix up 300 "parts" of air. ● **Nitrogen** makes up 78 percent of the lower atmosphere, so calculate 78 percent of 300:

0.78 x 300 = _____

Count out that many **beans** to represent **nitrogen**. ● Now, **calculate** the parts of **oxygen** by finding 21 percent of 300, since oxygen makes up 21 percent of the lower atmosphere:

0.21 x 300 = _____

Count out that many pieces of **popcorn** to represent **oxygen**. ● **Trace gases** are only 1 percent of the atmosphere. **Calculate** the parts of trace gases and count out that many **peas** to represent these gases:

0.01 x 300 = _____

Put all the parts of beans, popcorn, and peas into the jar, screw the lid on firmly, and shake the jar.

Activity B:

To show these percentages another way, construct a **pie chart**.

Materials Needed:

- ✔ **colored pencils**
- ✔ **compass**
- ✔ **protractor**

Your pie will have three "pieces," one each of **nitrogen**, **oxygen**, and **trace gases**. Remember that **a circle contains 360 degrees**. To find out how big your nitrogen piece will be, calculate 78 percent of 360 degrees. This is the number of degrees that will be in the nitrogen slice of the pie chart.

Nitrogen:

0.78 x 360 degrees = _____ degrees. *(Round off answer to nearest unit.)*

Use this same method to find out how large your oxygen slice and your trace-gases slice will be.

Oxygen:

0.21 x 360 degrees = _____ degrees.
(Round off answer to nearest unit.)

Trace Gases:

0.01 x 360 degrees = _____ degrees.
(Round off answer to nearest unit.)

With a **compass**, construct a circle with a radius of about 5 cm. Then use a **protractor** to figure the sizes of the angles and construct your pie chart. Be sure to label the various "pieces" of the atmospheric pie.

Questions:

❶ **Does it take very much carbon dioxide or other trace gases to warm the atmosphere?**

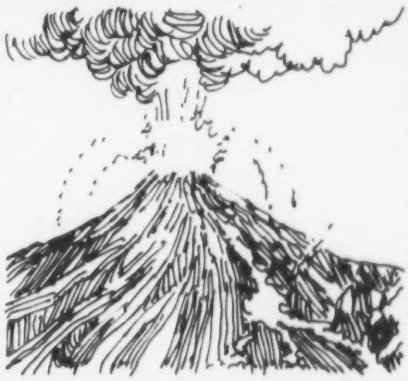
❷ **If humans add more carbon dioxide or other trace gases to the atmosphere, what might happen?**

❸ **You shook the jar to mix the gases. How does Nature mix the gases?**

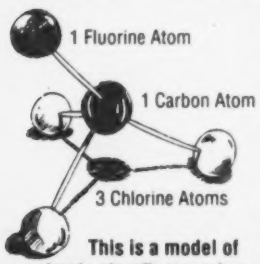
Why **Study** the Ozone **Layer?**

Ozone Chemistry:

Ozone forms a shield in the stratosphere that protects plant and animal life on Earth by absorbing much of the Sun's ultraviolet (UV) radiation. **It is a gas** (O_3) that is made of **three atoms of oxygen**. In the **stratosphere**, ozone is very reactive and is constantly being created and destroyed. Natural factors that affect the amounts of ozone present in the stratosphere include **wind** movements in the **middle atmosphere**, the amount of **solar activity**, and **changes in seasons**. For example, each **spring** in Antarctica (which is late fall in North America), the thickness of the **ozone layer** over the South Pole ***decreases***, forming an area of severe ozone ***depletion***, which is often referred to as the "**ozone hole**." As the Sun penetrates the polar air, the warmed air eventually creates new air movements and chemical reactions, bringing in more ozone and interrupting **processes** that destroy ozone. The **concentrations** of ozone increase and, by **summertime** in Antarctica, the ***hole no longer exists***.



Chlorofluorocarbons (CFCs) are chemicals used for a variety of purposes, including cooling in **refrigerators** and **air conditioners**. When CFCs escape, they are mixed by air motions in the atmosphere and are eventually transported into the **stratosphere**. There they **absorb UV radiation** and break apart, releasing an atom of **chlorine**. Under certain conditions, **the chlorine atom can destroy ozone** molecules through chemical cycles, depleting the protective "**ozone umbrella**" in the stratosphere. ***As humans have used more and more CFCs, the rate at which ozone is destroyed has been accelerated, and the balance between the creation and destruction of ozone has been changed.***



This is a model of a simple clorofluorocarbon ($CFCl_3$) molecule.

Ozone Loss:

Scientists have observed stratospheric ozone for several decades and have detected thin spots in Earth's protective ozone layer. In 1985, British researchers reported that the amount of ozone over the Antarctic at the beginning of each spring was less than expected. Since then, research has shown that this seasonal ozone hole occurs because the **very cold temperatures** over the South Pole, combined with the **presence of chlorine from CFCs**, decrease the amount of ozone. Although scientists do not understand the processes as well, more recent observations have indicated that ozone depletion also occurs in other regions of the world. For example, **ozone levels were at a record low over parts of the Northern Hemisphere during the 1992-93 winter**. Investigators believe this may be related to the eruption of the volcano on **Mt. Pinatubo** during 1991. The volcano spewed many chemicals into the atmosphere, including large amounts of sulfur dioxide. Through chemical reactions occurring in the stratosphere, the sulfur dioxide is converted to sulfuric acid. Small droplets of the acid may have played a part in the ozone depletion. ***Even before the Mt. Pinatubo eruption, there were significant losses in total ozone at nearly all latitudes except the tropics, and scientists suspect that chlorine from CFCs is a major contributor to the ozone loss.***

The graph on the front of the poster shows daily average amounts of **ozone** in the Northern Hemisphere recorded from ***1978*** through ***1993***. The ozone was measured by the Total Ozone Mapping Spectrometer, an instrument flown on **NASA's Nimbus-7** satellite and on a **Russian Meteor-3** satellite. The ***red line*** represents the ***1978 to 1991 ozone average***. ***Levels for 1992*** are indicated by the ***yellow line***, and the ***blue line*** shows the ***record-low levels*** of ozone measured in ***1993***.

The **global ozone map** on the front of the poster was created from data gathered by the Millimeter-wave Atmospheric Sounder, an instrument that flew on the **ATLAS 1 Space Shuttle** mission in the spring of ***1992***. The color-coded map indicates the **levels of ozone** over much of the globe during the period recorded by the mission.

Results of Ozone Loss:

Scientists are not sure what will happen if the ozone layer becomes thin all over the planet, but because they know some of the harmful effects of short-wavelength UV radiation on living things, they are concerned. **Even a hole over the Antarctic could have serious results.** The cold oceans of the Antarctic are filled with one-celled algae called **phytoplankton**, a name that means "*drifting plant*." ***All life in the ocean depends on these tiny plants.*** Through the process of photosynthesis, phytoplankton convert carbon dioxide and water into sugars and starches. ***Scientists wonder what the effect on the ocean's food web would be if the population of those plants were reduced by UV radiation.*** Also, these tiny plants remove carbon dioxide from the atmosphere: *more carbon dioxide in the atmosphere could raise its temperature*. This would affect all life on Earth, too. In addition, ***if stratospheric ozone decreases dramatically, humans may be exposed to levels of ultraviolet radiation that could increase the incidence of skin cancers and cataracts.***

Because the ozone layer plays such a big role in guarding our environment, it is very important that people learn about the processes involved in ozone production and depletion and that we make global decisions that will protect our planet and its atmosphere for generations to come. An example of this global cooperation is the ***Montreal Protocol***, an agreement that was signed by most of the world's developed countries in ***1987***. Because of reliable scientific data, such as that from detailed studies of the Antarctic ozone hole, indicating the strong likelihood that CFCs were damaging the ozone layer, the participating countries agreed to ***stop the production and use of CFCs by the year 2000***. Since 1987, more countries have joined the effort, additional chemicals have been targeted for phase-out, and the timetable has been shortened. **Many challenges still exist, and there is more to learn about the ozone layer, but the world's leaders have taken decisive action that will, hopefully, protect our global environment.**

Welcome to the "O" Zone!

Ozone, a gas located in the stratosphere, absorbs nearly all of the ultraviolet (UV) radiation from the Sun. In this way, **ozone protects life on the planet by preventing too much UV radiation from reaching Earth's surface.** Limiting the amount of UV radiation is important because **too much UV can burn skin, damage eyes, and cause skin cancer**. This is why people must wear sunscreens and protective clothing in sunlight. **Plants can be affected, too: if they are exposed to large amounts of UV radiation, they can be seriously damaged.** Scientists are doing extensive research to discover all the effects of UV radiation on both animals and plants.

Although ozone does a very important job, there are typically **only 1 to 10 parts of ozone in every million parts** of gas or particles in the **stratosphere**. In fact, if all the ozone molecules located in the stratosphere were compressed under the same pressure and temperature that exists at Earth's surface, they would form a layer only 2 to 5 mm thick! There are so few molecules of ozone that scientists measure the gas in **parts per million** (ppm).

Activity:

It may be difficult to imagine such small amounts, so try this activity:

Materials Needed:

- ✔ **3-m measuring tape**
- ✔ **cardboard box, about 60 x 60 x 60 cm**
- ✔ **scissors**
- ✔ **glue**

Procedure:

You are going to determine the volume of ozone that would be present in an area of the stratosphere that is the size of your classroom.

❶ **Measure** the length, width, and height of your classroom in centimeters.

❷ **Multiply** the three numbers together to find the room's volume in cubic centimeters.

❸ To find out how many parts of ozone you will need for the volume of your classroom, **divide** the cubic centimeters by one million *(move the decimal point six places to the left)*. For 10 ppm, multiply your answer by 10.

You will now make that number of cardboard cubes to represent the ozone volume.

❹ **Cut** the box into flat sheets of cardboard.

❺ **Divide** the sheets into 1-cm squares, marking the squares with a pencil.

❻ **Cut** out enough cardboard squares to form cubes about 1-cm high.

❼ **Glue** the squares on top of each other to form blocks. These blocks will represent parts of ozone.

❽ **Suspend** the cubes around your classroom on pieces of string to make a model of 10-ppm. ***This gives you some idea of the amount of ozone in the stratosphere.*** Remember that the rest of the space is not empty; it is filled with molecules and atoms of other gases and particles.

Question:

From what this investigation shows you, do think that it requires a great deal of ozone to absorb UV radiation?

Watt *Power!* Why *study* the Sun?

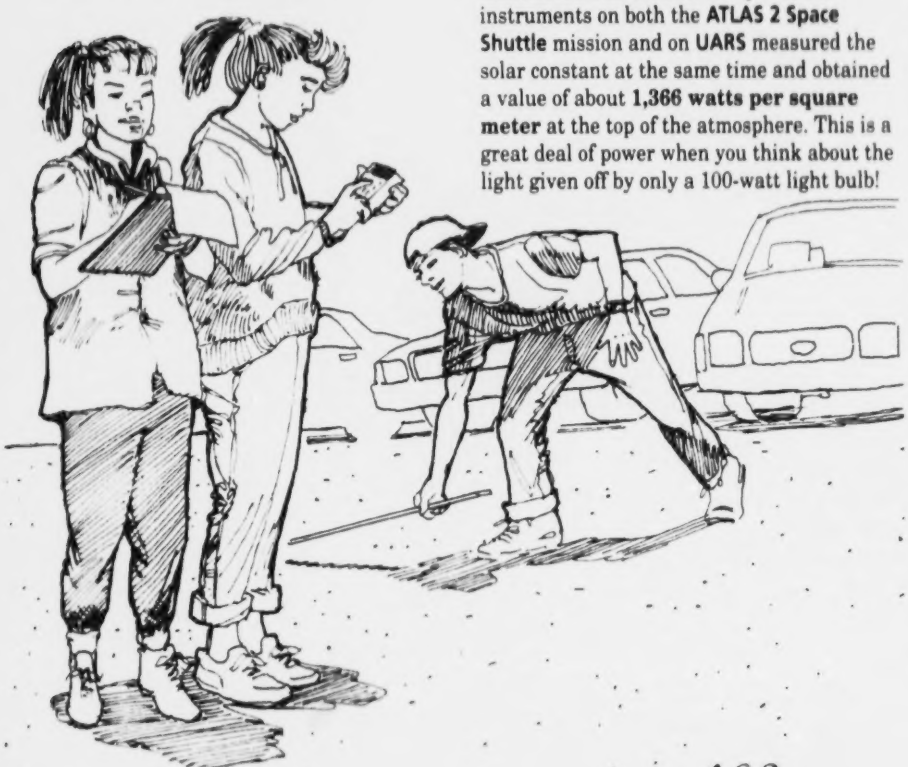
The ***power*** of the Sun's energy is particularly visible when there are prominences. **Prominences** are huge bright loops or arches of gas that are evidence of ***violent solar storms***. **Solar flares** are another kind of storm, but they are much briefer. Although short, solar flares are accompanied by increases in **X-ray**, **gamma ray**, and **ultraviolet** (UV) emissions by the Sun. **Sunspots**, which can be larger in area than Earth itself, are ***huge storms*** in the Sun's lower atmosphere, the **photosphere**.

All of these solar activities may affect Earth's climate, but we cannot know unless we study the Sun's energy over a long period of time. **The best place to study the energy beaming from the Sun is in space**, beyond the absorbing and reflecting effects of Earth's atmosphere. Scientists made some of their major discoveries about the Sun while occupying America's first space station, **Skylab**, in the 1970s. Researchers have continued this important work over the years. Now scientists pursue this research with the **ATLAS Space Shuttle** missions and with the **Upper Atmosphere Research Satellite** (UARS), measuring the Sun's total energy output and comparing it with past measurements and future calculations.

The Sun emits energy in different wavelengths, but that energy is not equally divided among the parts of the **solar spectrum**. *(The solar spectrum is the range of energies emitted by the Sun from low-frequency radio waves through visible light to high-frequency ultraviolet light and beyond.)* **Forty-one percent** of the Sun's energy is emitted in the **visible range**. **Fifty-two percent** is emitted in the **infrared range** and **seven percent** in the **"near" UV** — those that are closer in length to visible light. **X-rays** and the **shorter ultraviolet** wavelengths are only **0.001 percent** of the total energy emitted. At the other end of the spectrum, **radio waves** and **microwaves** make up about **0.0000000001 percent**.

Activity:

For a long time, scientists believed that the amount of energy streaming across the millions of miles of space from the Sun never changed. In fact, the power of sunlight reaching the top of Earth's atmosphere has been given the name "**solar constant**." However, scientists know the Sun's radiance is not "constant" at all — it does change slightly. **The graph running across the Sun on the poster indicates how solar activity (the number of sunspots) has fluctuated since 1940.** In April 1993, instruments on both the **ATLAS 2 Space Shuttle** mission and on **UARS** measured the solar constant at the same time and obtained a value of about **1,366 watts per square meter** at the top of the atmosphere. This is a great deal of power when you think about the light given off by only a 100-watt light bulb!



The key issue now is to determine exactly how much variation there is in the Sun's power and how the variations may affect Earth's climate. Investigators will continue to search for clues to this mystery.

To get some idea of the Sun's power in light bulb terms, complete this investigation:

Materials Needed:

- ✔ **pencil**
- ✔ **meter stick**
- ✔ **paper**

Procedure:

Using a meter stick, **measure** the **length** and **width** of a section of the school playground or parking lot *(about the area that would be occupied by three cars)*. **Multiply** these two figures to find the number of ***square meters*** in this area. Now **multiply** that area by **1,366** to find the approximate number of ***watts*** received by that area on a sunny day. Finally, **divide** the number of watts by **100** to find out the equivalent number of 100-watt light bulbs that would be required to equal the amount of power arriving from the Sun on a surface that same size. *Note: This is only an approximate calculation. Exact figures would depend on the time of year, the exact time of day, and the geographical location of the area being measured. Also, the amount of energy actually reaching your parking lot will be less than that reaching the top of the atmosphere because of such factors as cloud cover and gases in the atmosphere that absorb the Sun's energy before it reaches Earth's surface.*

Questions:

❶ How many 100-watt light bulbs are required?

❷ What does this tell you about the power coming from the Sun?

❸ How would your latitude affect the amount of the Sun's energy reaching the top of the atmosphere above you?

❹ Bonus Question: How many light bulbs would be needed to equal the Sun's energy received by Earth's entire surface? *(The area of Earth's disc is 127 trillion square meters.)*

Nothing but the Truth!

All the mysteries that **ATLAS scientists** investigate involve possible causes of apparent **climate changes**. For this reason, measurements made from **space** have to be compared with conditions on the **ground**, where the climate changes may be occurring. In this way, researchers can decide how solar and atmospheric changes compare with climate variations. Just as researchers need to make careful measurements in space over long periods, so do Earth-bound researchers. These surface measurements are called **ground-truth studies** and are used to establish whether a link between solar and atmospheric changes and weather actually exists and what kinds of changes are taking place. **These studies note weather events and keep track of possible long- and short-term changes.**

Activity:

You can be part of these important ground-truth studies.

Materials Needed:

- ✔ **daily newspapers**
- ✔ **chart on this page**
- ✔ **pencils or pens**

Procedure:

Check the newspaper and record information daily on **temperature highs and lows**, amount of **precipitation**, and **humidity**. Keep these charts, and figure weekly and monthly averages for your area as the year goes on. You may want to compare these with figures from previous years. You can use an almanac or old newspapers in the *microfiche* section of your **library** to find these figures if they are not available in your classroom.

To continue this activity: **Calculate** weekly, monthly, and yearly averages of **temperature** and **rainfall** in your area. **Make a bar chart** showing average temperatures for each time span.

Questions:

❶ What do you notice about seasonal variations in temperature highs and lows, precipitation, and humidity?

❷ Do these seasonal variations mean that the climate is changing?

❸ If you investigate measurements from past years, do changes necessarily mean that the climate is changing?

DATE	HIGH TEMPERATURE	LOW TEMPERATURE	PRECIPITATION	HUMIDITY
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
Daily Average				

NASA Resources for Educators

For more information on NASA education programs, teachers may contact the following:

NASA's Teacher Resource Center Network: Teacher Resource Centers (TRCs) contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, video tapes, telelecture programs, computer programs, lesson plans, and activities.

To offer more educators access to NASA educational materials, NASA has formed partnerships with universities, museums, and other educational institutions to serve as Regional Teacher Resource Centers. ***For the location nearest you, please contact the TRC serving your geographic region.***

NASA Teacher Resource Center
Mail Stop T12-A
NASA Ames Research Center
Moffett Field, CA 94035

NASA Teacher Resource Center
Mail Stop 8-1
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

NASA Educators Resource Laboratory
Mail Code ERL
NASA Kennedy Space Center
Kennedy Space Center, FL 32899

NASA Teacher Resource Center
Public Affairs Office (Trl. 42)
NASA Dryden Flight Research Facility
Edwards, CA 93523

NASA Teacher Resource Center
Virginia Air and Space Center
600 Settler's Landing Road
Hampton, VA 23669-4033

NASA Teacher Resource Room
Mail Code AP-2
NASA Johnson Space Center
Houston, TX 77058

NASA Teacher Resource Center
Building 1200
NASA John C. Stennis Space Center
Stennis Space Center, MS 39529

Education Complex - Visitors Center
Building J-17
Wallops Flight Facility
Wallops Island, VA 23337

NASA Teacher Resource Laboratory
Mail Code 130.3
NASA Goddard Space Flight Center
Greenbelt, MD 20771

NASA Teacher Resource Center for MSFC
U.S. Space and Rocket Center
P.O. Box 070015
Huntsville, AL 35807-7015

NASA Teacher Resource Center
JPL Educational Outreach
Mail Stop CS-530
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

NASA CORE: NASA's Central Operations of Resources for Educators was established for the national and international distribution of **NASA-produced educational materials in audiovisual format.** Educators can obtain a catalogue of these materials and an order form by written request, on school letterhead, to:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, EXT 293 or 294

NASA Spacelink: Spacelink is a **computer information service** that educators can access for news about current NASA programs, classroom activities, lesson plans, and publications. Users can access Spacelink with a computer and modem by calling **(205) 895-0028** or through the ***Internet*** at the following addresses:

spacelink.msfc.nasa.gov
xsl.msfc.nasa.gov
192.149.89.61

The data word format for direct and Internet access is 8 bits, no parity, and 1 stop bit.
For more information, contact:

Spacelink Administrator
NASA Marshall Space Flight Center
Mail Code CA21
Marshall Space Flight Center, AL 35812
Phone: (205) 544-6360

Liftoff To Learning video tapes, Video Resource Guides, and Mission Highlights fact sheets are available from the NASA ***Teacher Resource Center Network***. The text of Video Resource Guides and Mission Highlights is available from ***NASA Spacelink*** through the address listed.

Education Videoconference Series: NASA provides **staff development programs** for elementary and secondary school faculty through videoconferences. Program **information and educational materials** are available for participants.
For further information, contact:

Videoconference Coordinator
NASA Teaching From Space Program
300 North Cordell
Oklahoma State University
Stillwater, OK 74078-0422

Other available related resources:

Earth's Mysterious Atmosphere – ATLAS 1 Teacher's Guide with Activities, EP-282/11-91

Atmospheric Detectives – ATLAS 2 Teacher's Guide with Activities, EP-286/11-92

La misteriosa atmosfera de la Tierra – ATLAS Teacher's Guide with Activities, Spanish translation, EP-290/03-93

"Exploring Earth's Mysterious Atmosphere" – ATLAS 1 slide set

"The Atmosphere Below" – Liftoff to Learning videotape

"Mission to Planet Earth: A Program to Understand Global Environmental Change," PAM-556/2-94

Answers to student activities:

Going Up!

(1) Thermosphere - a "hot" color, such as red or orange. **(2)** Mesosphere - a "cool" color, such as blue or green. **(3)** Troposphere should be a medium color; stratosphere should be a warmer color. **(4)** The Shuttle travels in the thermosphere during the ATLAS missions. **(5)** ATLAS studies the middle atmosphere (stratosphere and mesosphere).

What a Gas!

Activity A: Nitrogen = 0.78 x 300 = 234; Oxygen = 0.21 x 300 = 63; Trace Gases = 0.01 x 300 = 3.
Activity B: Nitrogen = 280.8 degrees; round off to 281 degrees. Oxygen = 75.6 degrees; round off to 76 degrees. Trace Gases = 3.6 degrees; round off to 4 degrees. ***Note to teachers:*** Explain to students that the total for these is 361 degrees because each number has been rounded up.
Questions: (1) No. Trace gases are very effective. **(2)** More carbon dioxide may increase warming. **(3)** Gases are mixed by Earth's winds.

Welcome to the "O"-Zone:

No. If students do not reach a negative conclusion, point out the relative number of particles contained in the rest of the atmosphere.

Watt Power!

(1) Answers will vary. For a space measuring 9.5 m x 4.5 m, the answer is approximately 584 bulbs. **(2)** The amount of energy coming from the Sun is enormous. **(3)** Sunlight arrives at the equator at the most direct angle, so areas near the equator receive the most energy. **(4)** 1,735 trillion light bulbs. ***Note to teachers:*** This is *not* the total energy of the Sun. It is just the energy received by Earth's surface.

Nothing but the Truth!

(1) Temperature, precipitation, and humidity vary regularly with the seasons. **(2)** No. Seasonal changes by themselves do not necessarily indicate a change in climate. **(3)** Investigations covering many years are needed to indicate whether climate is changing. Observations of changes occurring over a few years may or may not have enough information.

WED 114/9-94